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Utilization of Blast Furnace Slag in Highway Improvement

By

CLARENCE EDWARD BARDSLEY

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Utilization of Blast Furnace Slag in Highway Improvement (*Abstract*)

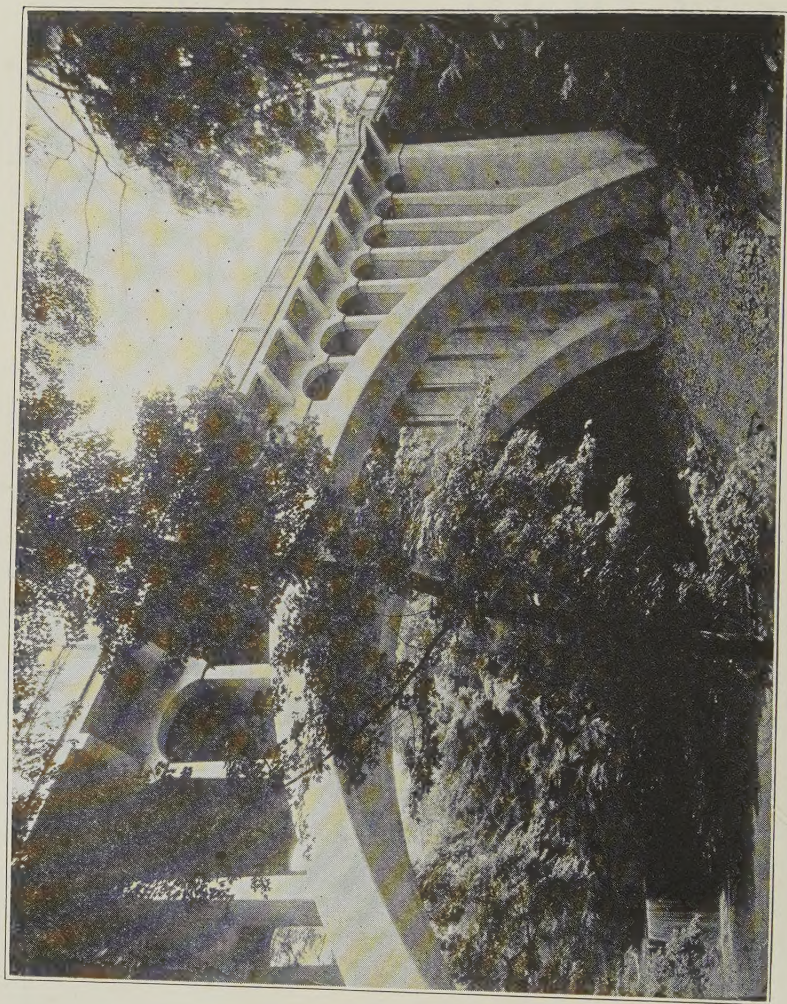
A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Science in the Uni-
versity of Michigan



CLARENCE EDWARD BARDSLEY
B. S. '20; C. E. '22; M. S. '24; Sc. D. '26

*Associate Professor of Highway Engineering and Highway Transport,
Summer 1926, University of Michigan; Assistant Professor
of Civil Engineering, Missouri School of
Mines and Metallurgy*

NATIONAL SLAG ASSOCIATION FELLOW
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Reinforced Slag Concrete Bridge in Youngstown, Ohio, called by all who have seen it: "The most beautiful bridge in America."



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PREFACE

THE NATURE AND PURPOSE OF THIS INVESTIGATION

A little over a year ago Professor Arthur H. Blanchard, head of the Division of Highway Engineering and Highway Transport at this University, secured thru the coöperation of Mr. Harry J. Love, Secretary, and the members of the National Slag Association, the establishment of a National Slag Association Fellowship in Highway Engineering at the University of Michigan.

The author of this dissertation, having a year's leave of absence from the University of Missouri for the purpose of study and research, was awarded this fellowship, and his problem was to determine the "Utilization of Blast Furnace Slag in Highway Improvement."

It was first proposed that a preliminary study be made of the properties of blast furnace slag as an aggregate in road construction, particularly in the construction of concrete highways, and then to run laboratory tests on blast furnace slag that would not duplicate the work of other investigators.

The preliminary investigation led to a study of a liberal percentage of the literature of the civilized nations of the world on the various aspects of the history, manufacture, utilization, and tests on blast furnace slag. Over three hundred books, periodicals, abstracts, and papers were read and their contents tabulated. Records of about fifty laboratory tests, dating from 1900 to the present time, were also secured. These tests, seemingly, cover every phase of the subject.

The problem at hand seemed insurmountable in that even members of the Slag Association, for years very familiar with the properties and possibilities of slag, seemed, when called into conference, not to know exactly what tests were desirable or what objective should be accomplished that would serve the best interests of the Association. This was largely due to the lack of knowledge, uncertainty, and wide variety of opinion apparently existing in the minds of specification-writing bodies in the United States.

As the result of the all-day conference of members of the committee supervising this investigation for the Graduate School of the University of Michigan, members of the National Slag Association, and the author, it was agreed that what was to be done was to interpret the many tests on blast furnace slag available, and to try and reach conclusions therefrom. This has been the chief objective of the author for the greater part of an academic year.

Much credit is due to Professor Blanchard for his untiring efforts in aiding the writer: for the use of material in his many publications, the fruit of his long and wide experience in the field of highway engineering; for his advice; and for the example he set in initiative and industry that one would envy, and in vain attempt to emulate.

To Professor R. L. Morrison, Associate Professor of Highway Engineering and Highway Transport, and Director of the Michigan State Highway Materials Testing Laboratory; and to Mr. A. E. Boyd, Instructor in Highway Laboratory Practice and Supervisor of the State Laboratories much credit is also due. It is due to their guidance in the proper procedure and interpretation of laboratory tests that the author has in a way tried to apply the principles inculcated.

To Mr. Frederick Hubbard, Consulting Engineer, Standard Slag Company, Youngstown, Ohio, and University Lecturer for the National Slag Association, acknowledgment is due for the pertinent points covered in his most valuable paper, "Manufacture, Properties, and Tests on Blasts Furnace Slag for Use in Highway Improvement."

Finally, it will be impossible to fully express the writer's gratitude to Mr. H. J. Love, Secretary-Treasurer, National Slag Association, with offices at Cleveland, Ohio, for permitting the writer to have free access to the extensive files of the Association. Without this privilege much valuable information would have remained buried.

Thanks is due the Committee of the Graduate School of the University of Michigan for their indulgence and timely suggestions.

CLARENCE E. BARDSLEY.

Ann Arbor, May 1st, 1926.

PREFACE TO ABSTRACT.

Hidden among the foregoing remarks lies the generosity of the Board of Curators of the University of Missouri, who, looking to the educational advancement of the faculty, allows its members the sabbatical year for the purpose of study or contact with an industry.

Since the preparation of this dissertation, through the guidance of Mr. Harry J. Love, Sec'y-Treas. National Slag Association, an additional bibliography on Blast Furnace Slag has been compiled, and with Mr. Love's permission, it is included in the appendix with acknowledgement.

Rolla, Mo. April 1st, 1927.

—THE AUTHOR.

CHAPTER I

HISTORY, MANUFACTURE, AND USE OF SLAG AS A STRUCTURAL MATERIAL

HISTORY

Psychologically the construction program of the human race since its beginning has been actuated by the same urge that continued the existence of the race itself: first, service for its immediate needs; and, second, a desire for durability, a desire that the builder's name would share the permanence of his work, and thereby achieve a sort of immortality.

For the first, man has dreamed many dreams and has made a great part of them come true. For the second, and hinging entirely on the first, he has searched the world for materials out of which to fashion his structures so that they would serve the purpose for which he designed them, and remain intact for many years after his death.

But the very nature of his structures, if they were build for more than temporary service, involved the use of bulky, heavy construction material in their composition, and the movement of such material complicated his plans greatly. The volume and weight of the possible building ingredients had to be considered in all of his calculations and his obvious escape from seeing his plans fail, his dreams shattered, and his work left incomplete—if ever begun—was in his building to avail himself of local materials.

In no detail of the registered effort of the human race to accomplish such ends in the construction filed is "locally available material" made more use of than in the building and maintaining of highways and pavements, and the structures supporting them.

In later times, in our own age, such tremendous quantities of many widely varied materials are blended into the highways that no one of the local road materials could be expected to supply the demand imposed by carrying out such building programs as have been accomplished during the past few years and will doubtless be continued far into the future.

But the utilization of a merely "locally available material" is not the register of its desirability or suitability measured in terms of its service life. The final answer to the question of the durability of any highway material cannot be made until this material has been given an ample service test.

If the structure being considered, for instance, is a section of pavement or highway; then such factors as volume of traffic that is to pass over it. The kind of traffic, the speed of the units, their possible impact, and their individual weight; also the class of supporting sub-soils, the drainage, climate conditions, temperature range, and

the feasibility and adaptability of maintenance—all these must be studied and weighed before the type of construction and combination of construction materials is decided upon. When bridge design as a part of highway construction is encountered, then all the above details and many more come up for scrutiny and deliberation.

Among the locally available materials for bridge, highway, and pavement construction and maintenance in many parts of the United States adjacent to the iron and steel centers, is blast furnace slag. The use of this material in isolated examples of highway construction of the simpler types has extended back for periods that approximate one hundred years.

Within the past thirty or thirty-five years, however, and within reasonable shipping range of its points of production, the utilization of blast furnace slag has become common practice. Its use has extended to the degree that it is incorporated in practically every type of highway structure ever designed and the volume of square yards of running miles of highways and pavements in existence in which it is a component part has grown to immense figures. Bridge structures in which slag has been used are numbered in hundreds.

The writer has made a thorough review of the literature pertaining to the use of this material, and has made a digest of the technical data developed by many testing laboratories both in the United States and abroad. This information, supplemented by personal inspection of several crushing plants, numerous bridges, and many miles of highways built in part, or wholly, of blast furnace slag, has given him an unusually close view of an entire industry about which there is relatively little known.

In spite of the fact that his investigation pertains more directly to the use of blast furnace slag in highway construction and maintenance, it is not out of place to briefly sketch some pertinent points regarding the industry which produces the material. There are exactly fifty plants in the United States devoted to crushing and screening blast furnace slag, and all of them are located east of the Mississippi River. There are probably two thousand people engaged in the industry of processing and marketing the output of these plants. Their combined output in 1925 was approximately eight million tons of commercialized slag; and, it is estimated, that fully sixty-five per cent of this product was consumed in highway construction.

In reviewing the literature and data, and in inspecting the plants and the examples of construction where slag was involved, a definite procedure was maintained for isolating the ascertainable facts regarding, not only the material itself, but the finished product of which it was a component part. To determine these facts the following "List of Characteristics" was invariably applied to each example found.

TABLE I.
CHARACTERISTICS

Abrasion	Elasticity	Shear
Absorption	Expansion	Size
Accessibility	Fatigue	Stability
Age	Flow Sheet	Solubility
Bending	Fracture	Specifications
Bond	Gradation	Specific Gravity
Bulking	Hardness	Surface Area
Cementation	History	Strength
Chemical	Homogeneity	Tensile
Cleanliness	Impact	Thermo-conductivity
Corrosive Qualities	Moisture	Torsion
Crushing	Organic Matter	Toughness
Definition	Light and Heavy	Uniformity
Density	Permeability	Voids
Desirability	Petrographic	Weight
Durability	Rupture	Weathering
Economy	Shape	Workability
		Yield

The technical literature of many countries contain many references to the use of blast furnace slag in highway construction in some form or another. It may play its part as a raw material in true portland cement manufacture, as an admixture in portland cement clinker, intimately ground and reduced in the finishing processes, or as a slag cement. It may also be utilized in moulded blocks. It may be crushed and screened and rolled into bases where it sometimes becomes cemented together by its own binding qualities. Slag also may be held in bituminous mixtures or cement concrete so that it presents a strong support for vehicular traffic. Roads thus constructed do not deteriorate readily, and as time elapses, they may be maintained at low cost.

Blast furnace slag is used very widely throughout the world as a highway construction material. Some conception of the wide extent of its use can be obtained from a brief review of the following: "Streets and Highways," 1891, by the United States Department of State; "Cement, Limes, and Plasters," by E. C. Eckel; "Use of Slag in the Building Industry," 1920, by Dr. A. Guttman; and from the writings of various investigators among whom are Mr. Kenneth Gardner, C. E., of Cleveland, Ohio; and Mr. Y. Emori, City Engineer of Tokio, Japan. From these sources we learn that slag is used in highway construction in England, Spain, Holland, Austria, Germany, France, Czecho-Slovakia, Russia, Belgium, Switzerland, Chile, China, Japan, and Sweden.

It takes but a slight stretch of imagination to draw an analogy between blast furnace slag and volcanic lava, and it is interesting to check the association that is clearly drawn by many writers between the two as construction materials.

During the time of the Roman Empire, Pliny and Vitruvius mentioned pozzuolana used in place of sand in the construction of various aqueducts and viaducts, which have stood for centuries, and parts of which are still in existence. They are fitting monuments to engineering skill and the durability of the material. At Pozzuola, a breakwater, consisting of more than twenty arches, was constructed of brick and faced with stone, the mortar consisting of pozzuolana and common lime. Although constructed over 1800 years ago, thirteen arches still remain standing above water.

Pozzuolana is of volcanic origin and was produced by molten lava coming in contact with water during an eruption. Its chemical composition is mainly silica, alumina, iron, and a varying percentage of lime. This material is not unlike modern granulated blast furnace slag in its appearance, properties, manufacture, and use. In Germany, in particular, pozzuolana and slag are now used extensively in the manufacture of pozzolina and portland cements.

From Roman times until the middle of the eighteenth century not much progress was made in the use of slag as a building aggregate. In Germany in 1770 granulated slag was recognized as furnishing a material of very superior quality for the making of mortar as compared with common sand. From about 1820 to 1870 some success was attained in England in the casting of molten slag into blocks for road paving. Records are available that in 1831 roads were constructed of blast furnace slag in Missouri, and in 1849 in Virginia. These roads were built contiguous to the charcoal furnaces of the vicinity and they are still in use. In 1870 Mr. Luurman, a prominent furnace engineer, began the manufacture of slag brick at Osnabruck, Germany, using about 90 per cent of granulated slag and 10 per cent lime. These bricks proved to be well adapted to all kinds of subaqueous and subterranean work as well as to superstructures and they were used in some paving. In 1873, the Tees Slag Company of Middlesboro, England, manufactured slag brick using a different process and using a pozzolina cement as binder. These brick were used in a number of important structures.

The manufacture of slag paving and building brick is now carried on in all of the iron producing districts of Europe. This industry, together with its use in cement manufacture and aggregates, consumes a large part of the slag produced.

The manufacture of slag cement, which consisted of a mechanical mixture of dried and ground granulated slag and lime, was tried out in a number of points within the United States. The first venture was made in Chicago in 1899, and after that time several plants came into operation. They were located at Birmingham, Alabama, Sharon, Pennsylvania, and at Youngstown, Ohio, but at the present time there is but one plant in existence within the United States. Practically all of the product of these plants was and is being placed in highway construction.

The Ford Motor Company, whose manufactured portland cement is quite universally recognized as of a high grade, utilizes blast furnace slag as one of the ingredients in the raw mixture. During the past

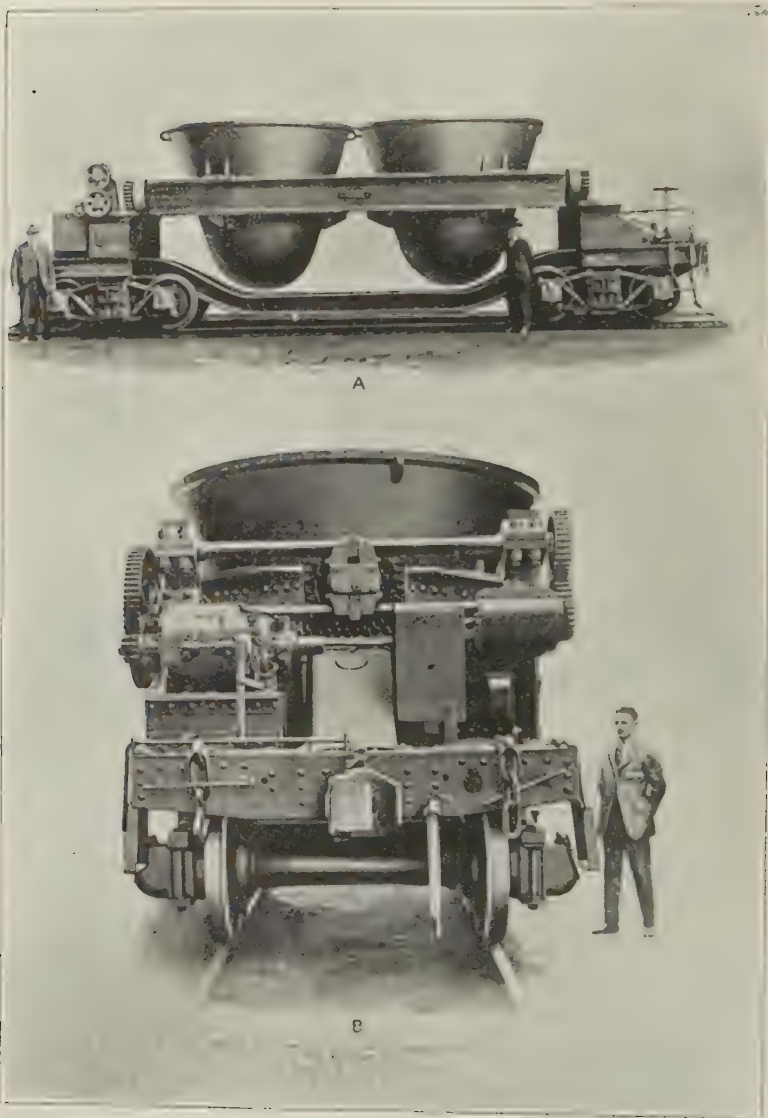
year this company developed a new process for making a product known as "Ford Cement." In the initial mixture about twenty-five per cent of slag is combined with the lime and clay. A cement plant duplicating the Ford process is under construction at Buffalo at the present time.

About 1907, shipments of moulded slag brick produced in Birmingham, England, began arriving in the eastern cities of the United States and, though their importation today has ceased, there are probably a million and a half square yards of the original pavements constructed of them now in use in New York City, Philadelphia, and the city of Washington. The high cost of labor following the World War, the large demand for slag paving brick at home, and the relatively high cost of transportation of bulky and heavy shipments raised the cost for use in the United States of these brick to a prohibitive figure.

The possible volume of production of crushed and screened blast furnace slag is in an established ratio with a production of pig iron. Although the individual furnace, or the furnaces of an entire district, may vary greatly, it is a safe estimate to anticipate that throughout the industry as a whole, there will be a slag production of fifty percent of the tonnage represented by the pig iron.

There are almost four hundred blast furnaces in the United States, practically all of which are located east of the Mississippi River, and on a general average there are eighty per cent of them in operation.

Since the year 1800, the year for which we have the first authentic record, the production of pig iron and the accompanying slag has increased enormously. In that year 53,908 tons of pig iron was produced. The accompanying table will show the amount produced in recent years.



Electrically Dumped Slag Ladle or Cinder Car

PLATE II

Courtesy of The Wm. B. Pollock Co.

TABLE II

PRODUCTION OF PIG IRON AND BLAST FURNACE SLAG

	Total all types of Pig Iron	Blast Furnace Slag Estimated
1910.....	27,300,000	13,650,000
1911.....	23,650,000	11,825,000
1912.....	29,700,000	14,850,000
1913.....	31,000,000	15,500,000
1914.....	33,300,000	11,650,000
1915.....	29,900,000	14,950,000
1916.....	39,400,000	19,700,000
1917.....	38,600,000	19,300,000
1918.....	39,100,000	19,550,000
1919.....	31,000,000	15,500,000
1920.....	36,900,000	18,950,000
1921.....	16,000,000	8,350,000
1922.....	27,200,000	13,600,000
1923.....	40,000,000	20,200,000
1924.....	31,100,000	15,050,000
1925.....	36,750,000	18,375,000

MANUFACTURE

Mr. H. M. Sharp, Manager of the France Stone Company of Toledo, Ohio, states: "Slag and pig iron are industrial Siamese Twins. True, their respective fields of usefulness are widely divergent, but they come into existence identically at the same instant and it is becoming an established fact that when placed to certain uses the slag serves as admirably, even if less spectacularly as its one-time twin, in other fields." In other words, pig iron can not be produced without slag; and, since commercial uses have been established for it, slag is ceasing to be termed the waste or by-product of the blast furnace; and has attained the status of a standardized construction material. It is well known among furnace engineers that the better the slag is made, the better the resulting pig iron, so the modern blast furnace is now run for two results: good slag and the best iron.

A blast furnace is essentially an elongated steel barrel 90 to 100 feet in height and from 25 to 35 feet in diameter with the bulge much nearer the bottom than the center of the barrel. It is lined with fire brick at the upper end and with hollow water-cooled bronze blocks at essential places for thermostatic adjustment. There is a fire brick basin below. The barrel is filled with alternate layers of coke, limestone, and iron ore. An intensely hot blast of air is introduced

near the bottom. Then after the fuel is ignited from the bottom and the blast turned on, the temperature in this stack varies from approximately 300° F. near the top to from 3500° F. to 4000° F. at the bottom. The following changes take place as the process continues:

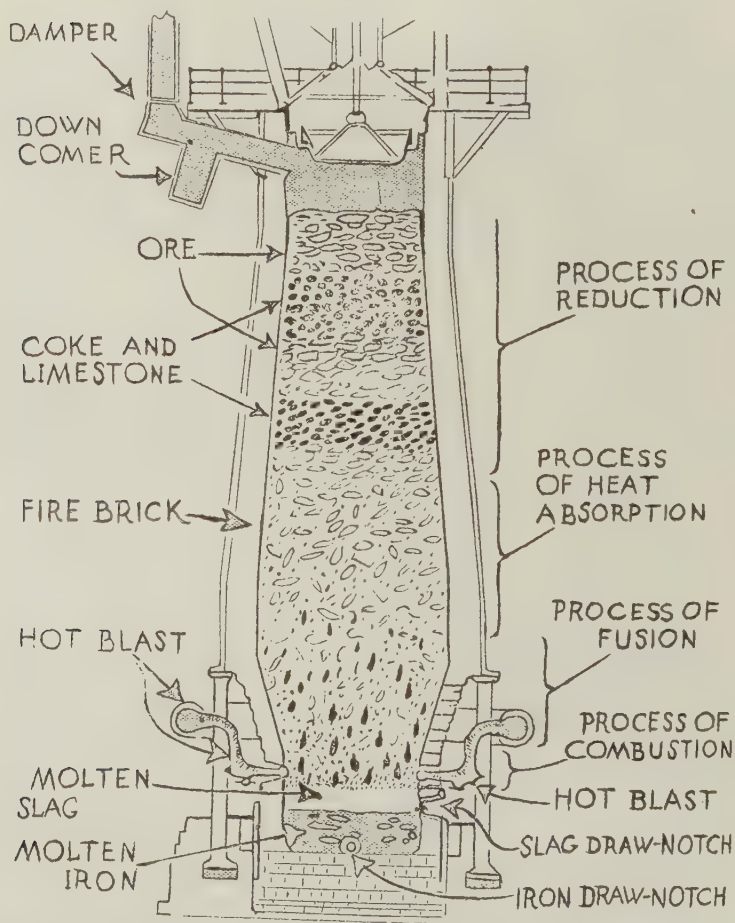
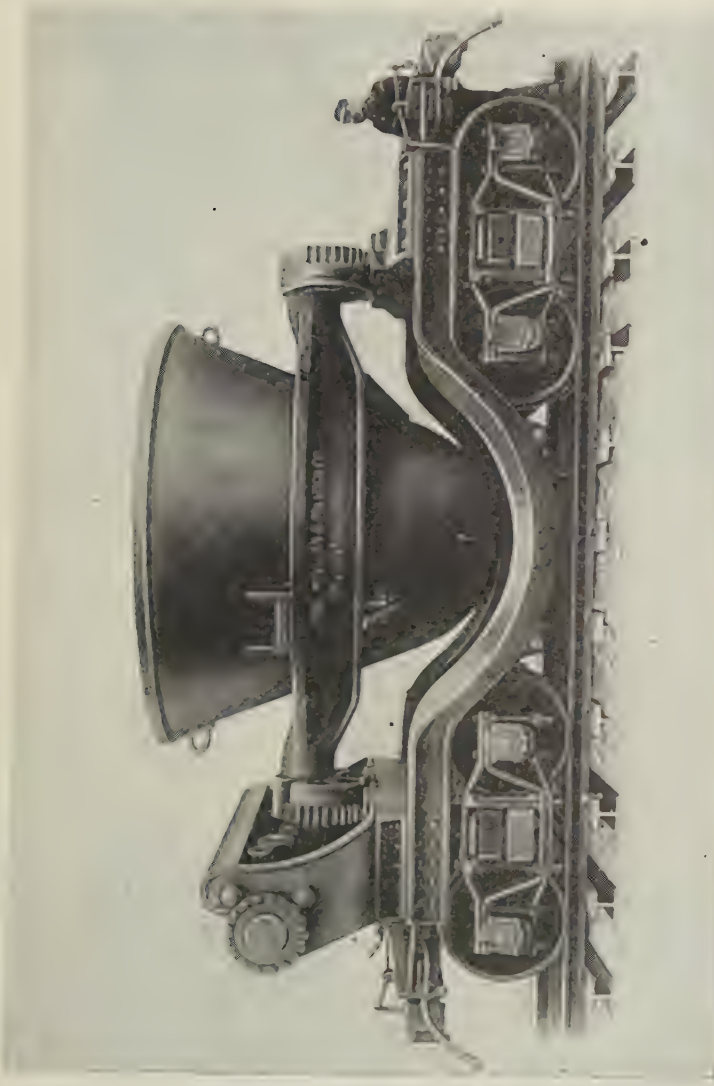


Diagram of Blast Furnace, the Charge, and the Process in the Manufacture of Pig Iron and Blast Furnace Slag.



Slag Ladle.

—Courtesy of The Wm. B. Pollock Co.

PLATE IV

As the temperature increases, the silica and alumina, which are in combination with iron in its ore state, become free and combine with the limestone. The iron, reduced from its ores by Carbonic Oxide or some other reducing agent, descends towards the bottom of the furnace. With it also descends a molten combination of earthy matters, or gangue of the ore, and the flux. This mixture floats on the surface of the molten pig iron, and like the iron is drawn off from the basin at the bottom of the barrel or blast furnace. This new lighter combination is called "Blast Furnace Slag."

As the following table will show, it, in its component parts, compares quite favorably with Portland cement. It has identically the same component parts only in different proportions.

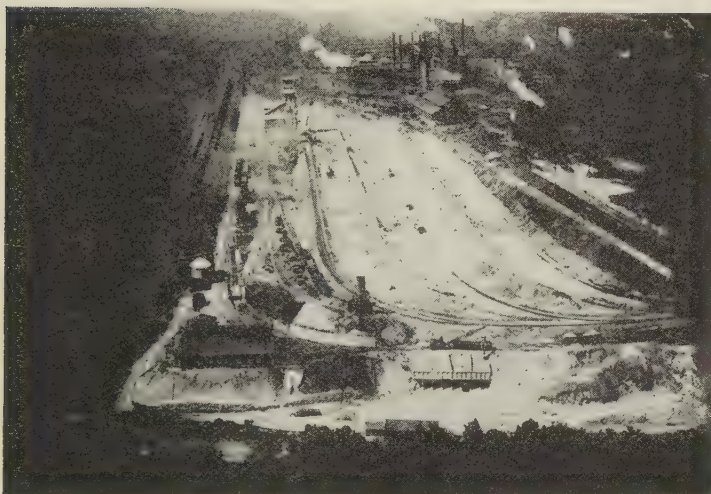
TABLE III
RANGE IN CHEMICAL COMPOSITIONS OF BLAST
FURNACE SLAG AND PORTLAND CEMENT

	Blast Furnace Slag Percent	Portland Cement Percent
Silica.....	32 to 48	20 to 25
Lime.....	17 to 45	57 to 65
Alumina.....	8 to 20	5 to 29
Magnesia.....	1 to 12	.065 to 3
Iron.....	1 to 3	2 to 5
Sulphur Compounds.....	0.5 to 2.5	1.25 to 2.0

The committee, E-5, on Aggregates of the American Concrete Institute, has developed probably the best existing definition of Blast Furnace Slag in the literature pertaining to that material. It states that, blast furnace slag is the non-metallic product consisting essentially of silicates and aluminosilicates of lime which is developed simultaneously with iron in a blast furnace.

The variations in chemical composition of the slag are due to the grade and kind of ore and to the furnace burden necessary to the reduction processes. This table simply shows the outer chemical limits of structurally satisfactory slag. In the average, the range is much less than indicated. Of these chemical components of slag, the silica comes chiefly from the ore; lime and magnesia from the flux or limestone; alumina and sulphur from the ore and fuel. The greater per cent of the sulphur is consumed in the process of combustion and the small percentage of sulphur remaining is inertly combined in sulphides and sulphates.

There are two openings or "notches" in the base of the blast furnace. The slag is drawn off by gravity through the upper notch, which is above the level of the molten iron. It is conducted to the slag pits adjacent to the furnace, or, if near by pits are unavailable, it is run into ladles on standard railway trucks (see plate I) and hauled to a point where storage space is available, where it is poured out on the land or in modified pits to cool. The molten iron is drawn off at the lower notch of the furnace basin. Once a blast furnace is "blown in" the process of reduction is continuous. A flow sheet or diagram showing the essential parts of a blast furnace and of the furnace charge is shown in Figure 1.



Aeorplane view of a modern Slag plant layout of modified pit system.

PLATE VI

The slag is in a molten stage when it leaves the blast furnace and in this condition is delivered to the slag operator in 12 to 20 ton quantities every few hours continuously for 24 hours a day, month in and month out, for periods of from 2 to 5 years. It is imperative that the first thing to be done is to cool the slag down slowly some 3500° F. to atmospheric temperature. This is done by pouring super-imposed layers into pits which have the capacity to handle the furnace's

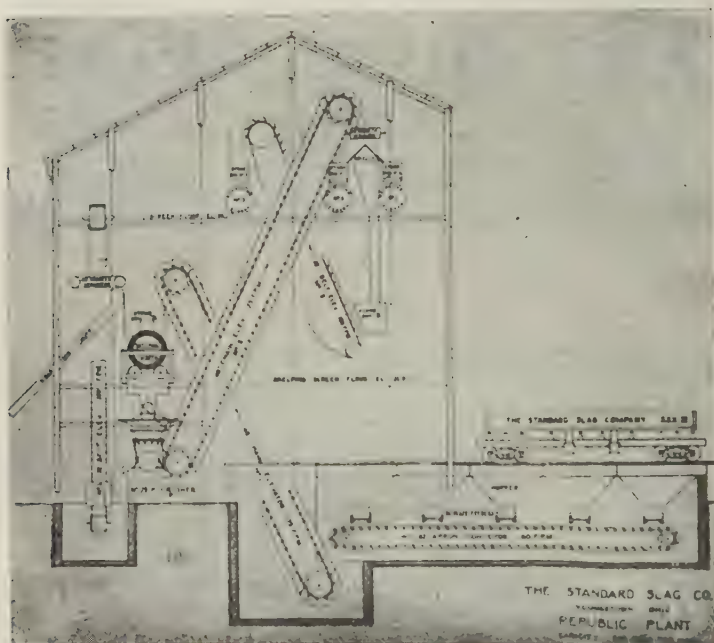


Section of modified Slag pit partially excavated and indicating clearly the well defined stratification that occurs when Slag is processed in this manner.

PLATE VII

production of slag for periods ranging from a few days to several weeks. Granulated slag is made by quickly cooling the slag with water. This process granulates it into small beads.

The air-cooled blast furnace slag is, when cool removed from the pits or banks by a steam shovel, loaded upon cars, and taken to the crusher. In the more modern plants, the pit or rough slag is fed into the crusher at a given rate by means of a mechanical feeder, the purpose being to avoid overloading the screens and impairing their efficiency.



Cross section of layout of modern Slag crushing plant.

PLATE VIII

Gyratory crushers are usually used. Care must be taken that no large iron pieces reach the crusher. These are removed by the mechanical-feeder attendant. The operation of elevating, screening, sizing, conveying, and storing the slag is similar to that of crushed stone. No washing is necessary.

There is little to distinguish a slag crushing plant from any other large crushing plant except that it has installed one, and often two, powerful magnetic separators. These separators are located in the pulley wheels at the ends of the conveyor belts so that they can catch any pieces of metal before they enter the revolving screens. These separators are designed to extract any piece of slag that contains any metallic iron. These pieces of slag are again run thru the furnace.

The foregoing is a general description of blast furnace operation and the mechanical processes utilized in the production and preparation of commercial slag. The following is a flow chart showing the typical slag crushing and screening plant operations just described. The capacity of these slag plants ranges from 300 to 4000 tons of crushed and screened slag a day.

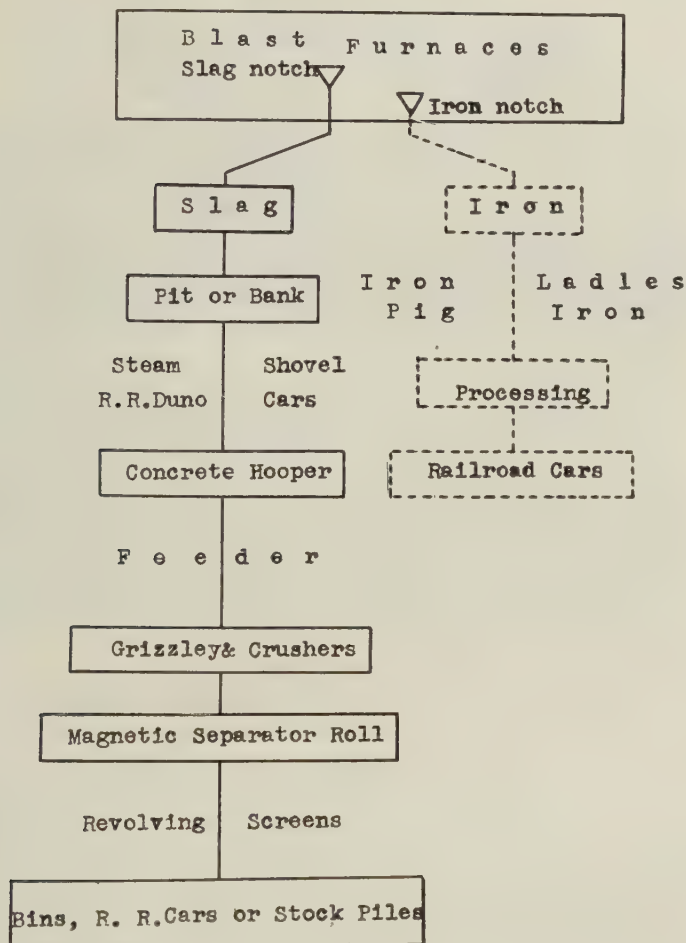


Diagram or Flow Chart of Typical Slag Crushing and Screening Plant

Fig. 1.



This small bundle of tie-wires dropped into a column form that was filled afterwards with Slag concrete. They were found fourteen years afterwards in this condition.

PLATE IX

DESCRIPTION OF COMMERCIAL BLAST FURNACE SLAG.

After slag has gone through the crushers and has been screened, it is a finished commercial product. It is free from dirt and foreign matter and can be furnished in any reasonable gradation. Commercial slag, when it reaches the market, is grey in color. The individual particles are roughly cubical in shape and there are no elongated or thin pieces present.

Slag has more bonding surface area per unit volume than any other commercial mineral aggregate. This is on account of the countless bubbles of gas that were entrapped in the molten material when it solidified. The process of breaking the larger fragments in the crushing plant has cross-sectioned these bubbles so that commercial slag is pitted on all its faces. However, one must not get the notion that blast furnace slag is like a sponge in that these pits or vessicles will absorb water and saturate the material. Such a characteristic might be disastrous in freezing weather. Slag has no such quality. Each pit is individually developed, as stated above, and is not connected with its neighboring pit. An inspection of the commercial product will make this quite apparent, and numerous tests for absorption verify the fact. Exceptionally light pieces of slag, selected on account of their porousness, have floated in laboratory tanks for periods up to nine years, apparently indicating no absorption whatever. The average of hundreds of samples of blast furnace slag shows that its range in void space is from 38 to 46 per cent for crushed and screened material passing the $1\frac{1}{2}$ -inch screen and retained on a number 4 sieve.

Blast furnace slag from various parts of the country varies considerably in weight, but the average plant produces slag weighing over 70 pounds per cubic foot in the above gradation. Very light honeycombed pieces of slag can be picked that weigh as low as 56 pounds per cubic foot, a few pieces of which will float on water. Heavy solid pieces weighing from 90 to 100 pounds per cubic foot can also be found, but bear in mind that these light and heavy pieces do not constitute average commercial product.

The actual physical, chemical, and service tests to determine properties of blast furnace slag are given in the complete report.



Thin curtain wall of reinforced Slag concrete being demolished after fifteen years service in Cleveland, O. The steel was in perfect condition.

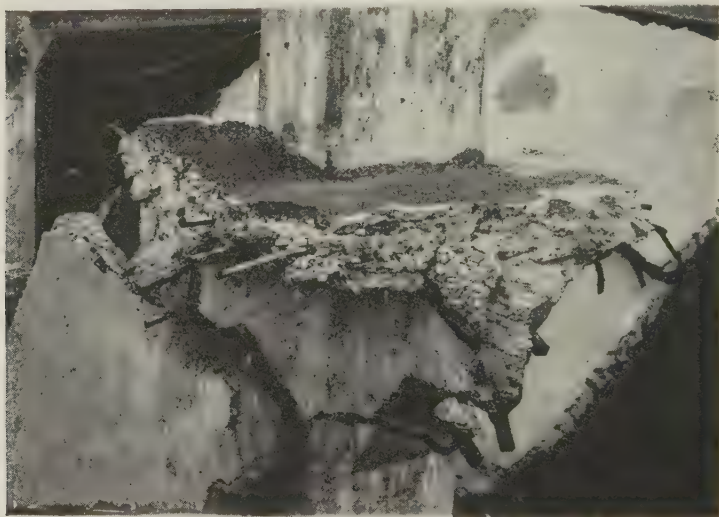
PLATE X

SLAG AS A STRUCTURAL MATERIAL.

Records show that nearly a century ago slag was used in water-bound macadam road construction in the United States. Neither is its use as a structural material new. Blast furnace slag has been used as concrete aggregate for many years in all types of construction. The earlier use of slag for this purpose naturally developed in the furnace districts, where the problem of its disposal was acute, and where conditions were such as to warrant a trial of the material for any purpose to which it might seem adapted. Records show that slag concrete was used in and about iron furnaces in the Birmingham, Alabama, district nearly 40 years ago, first in plant and machinery foundations and later for all kinds of concrete work. In the Lehigh district of eastern Pennsylvania, slag concrete was used by the Philadelphia and Reading Railroad in 1890. The Atlas and other cement companies used slag in 1895 in the Lehigh, Pittsburg, Cleveland, and

Chicago districts. So the continuous commercial use of slag concrete dates back to the early nineties.

One of the earliest reinforced slag concrete buildings was erected in Philadelphia in 1897. When this building was razed in 1913, both the concrete and reinforcement were in excellent condition. This condition was also found to exist when the Ulmer Building and the Higgins Building were torn down in Cleveland after standing 16 and 17 years, respectively. The steel in both cases was in as good condition as it was the day it went in. Railroad bridges and culverts have been built of slag concrete since the use of slag was first attempted. Messrs. John S. Brodie, Civil Engineer, Street Department of Liverpool, and E. P. Hooley, County Surveyor, Nottingham, state



REINFORCING STEEL EMERGING FROM SLAG CONCRETE IN HIGGINS-BABCOCK BUILDING, CLEVELAND, O., AFTER HAVING BEEN EMBEDDED FOR FIFTEEN (15) YEARS
PLATE XI

that blast furnace slag has served in England for the past 20 years as the mineral aggregate of a bituminous preparation known as Tarmac. Slag, due to its pitted surface, bonds with the bitumen better than does any other mineral aggregates. Hundreds of thousands of square yards of this material have been laid in England, much to the alarm and dissatisfaction of the crushed stone producers. It gives unparalleled service as a pavement under heavy traffic. Slag is being used in increasingly large quantities in the United States in the construction of bituminous pavements as a result of the success attained in certain districts in the British Isles.

Air-cooled blast furnace slag, crushed and screened to a specified size, has been recommended by the highest authorities in highway and pavement construction both in Europe and America. It is estimated that slag has been used in over eight thousand miles of

improved highways in the United States. Practically all of the slag concrete roads in the United States are in seven states, Ohio, Pennsylvania, Georgia, New York, Indiana, Alabama, and West Virginia. Ohio alone has over two hundred miles of slag concrete highways, and Pennsylvania has sixty.

Slag concrete has been used in the construction of over seventy-five highway and railway bridges in the United States ranging in length from 3187 feet to 18 feet, in width from 72 feet to 18 feet, and in height from 14 feet to 195 feet; in number of spans or arches, from one to forty-four; and in the tonnage of slag used, from a few tons to 30,000 tons in a bridge. These slag concrete bridges carry general traffic, trunk line traffic, trolley and steam railway lines, and combination of traffic.

In several states; Ohio, Florida, Georgia, Illinois, Alabama, South Carolina, Pennsylvania, Connecticut, and New York, slag has been used in the construction of hundreds of buildings. The records show banks, office buildings, stores and offices, department stores, city halls, court houses, fire stations, factories, warehouses, storage buildings, theaters, schools, colleges, churches, hotels, hospitals, apartments, and farm buildings. That slag has been used in building construction in other states would undoubtedly be evident if the records were at hand.

Records are available to show that nearly one hundred railroads and electric railways use slag in concrete construction and for ballast.

Also documentary evidence is available describing numerous factory and power-plant chimneys constructed of slag concrete, many over 150 feet in height, the highest being 273 feet.

The foregoing facts clearly indicate that slag concrete has been successfully used in reinforced concrete construction, and has served admirably in all types of highway construction.

Crushed and screened air cooled blast furnace slag is according to the size card of a commercial producer available in the following sizes:

TABLE IV

<i>Use</i>	<i>Sizes in Inches</i>
Telford Road Base.....	4 to 6
Road Base.....	3 to 4½
Small Macadam.....	2 to 3¼
Small Ballast.....	1 to 2¼
Small Concrete.....	¼ to 1
Chips.....	¼ to ¾
Roofing.....	3/16 to 3/8
Sand.....	0 to ¼
Large Macadam.....	2 to 4½
Large Ballast.....	1 to 3¼
Large Concrete.....	¼ to 2¼
Screenings.....	0 to ½
Steam Shovel Run.....	0 to 6 or 8
Crusher Run.....	0 to 4½

The following is a summary of the limitations placed on slag for construction and maintenance as compiled from the 1926 specifications of fifteen State Highway Departments, the U. S. Bureau of Public Roads, the Concrete Institute, and the American Society for Testing Materials, and the Portland Cement Association:

TABLE V.

LIMITATIONS ON SLAG AS AGGREGATE IN CEMENT CONCRETE AS OF JANUARY 1st, 1926.

State organization	Weight.	Age.	Sulphur.	Physical Limit	Base.	Wear.	Struct.
Ohio (a) . . .	70	.....	.....	Soundness.. 12 % Wear.	.....	Wear..	Struct.
(b) . . .	65	.....	.....	Soundness.. 15 % Wear.	Base..	.....	.....
W. Va. (a) . .	70	6 mos. . . . .	.....	Soundness.. 10 % Wear.	.....	Wear..	Struct.
(b) . . .	70	6 mos. . . . .	.....	Soundness.. 15 % Wear.	Base.	.....	.....
Tenn.	75	6 mos.	1.5 %	.....	.....	.....	Struct.
Pa.*.	75	6 mos.	.....	.....	Base.	.....	.....
N. Y.	70	.....	.....	10 % Wear	Base.	Wear	Struct.
Ala.	75	6 mos.	1.5 %	Soundness	Base	Wear	Struct.
Ala. . . . .	.....	.....	.....	Coef. 5.	.....	.....	.....
Miss.	75	6 mos.	.....	.....	Base	.....	Mass.
Ind. (a) . . .	80	.....	.....	.....	Base	Wear	Struct.
(b) . . .	75	.....	1.5 %	.....	Base.	.....	.....
Ky.	75	.....	1.5 %	.....	Base	.....	Struct.
N. Mex. . . .	75	6 mos.	1.5 %	.....	.....	.....	Struct.
N. Car. . . .	75	Suit.	1.5 %	10 % Wear	Base.	.....	.....
Ga.	70	6 mos.	1.5 %	Coef. 5.5	Base	Wear	Struct.
Fla.	75	6 mos.	1.5 %	Coef. 4	Base	.....	Struct.
Bur. Rds. . .	70	6 mos.**	.....	.....	Base	Wear	Struct.
A. S. T. M. . .	70	.....	.....	.....	Base	Wear	Struct.
A. S. T. M. . .	75	.....	.....	.....	Base	.....	Struct.
A. C. I. . . .	70	.....	.....	.....	Base	Wear	.....
P. C. A. spec- tion.	if less slag	under wa-	ter-cement	t ratio theor-	y for b-	uilding	construc-
Fed. Brd. . .	70	6 mos.	.....	.....	Base	Wear	Struct.
(Subject to Allegheny	correction)	n)	.....	.....	.....	.....	.....
Co. Pa. . . .	70	6 mos.	.....	12 % Wear	Base	Wear	Struct.

The Joint Committee on Specifications for Concrete and Reinforced Concrete, composed of representatives from the American Society for Testing Materials, American Concrete Institute, American Society of Civil Engineers, Portland Cement Association, and American Railway Engineers Association, does not mention slag in its latest tentative specification published in 1924. This report appeared on page 320 in the Proceedings of the American Society for Testing

*Pennsylvania—penalized by volume—6½ to 7½.

**Or less if suitable.

Materials for that year. However, all the contributing bodies to this Committee either have developed specifications of their own for the use of slag, or have copied specifications of other Societies which do include slag, so that the absence of slag in the Joint Committee report is a matter of relatively small importance—a paradox which will eventually fail to exist. In fact, three of the member societies, the American Society for Testing Materials, the American Concrete Institute, and the American Railway Engineers Association have recommended that slag be admitted to the specifications of the Joint Committee.

The following tables are symposiums of the limitations on slag in bituminous and macadam road construction as specified by various state highway departments and engineering societies as of January, 1926.

TABLE VI

LIMITATIONS ON SLAG IN BITUMINOUS CONSTRUCTION
AS OF JANUARY 1st, 1926.

State	Weight	Age	Sulphur	Physical Limit	Base	Wear	Binder
N. Y.	70			10 % Wear		Bit. Mac.	
Fla.	75	6 mo.	1.5 %	Coef. 4		Bit. Mac.	Yes.
Alleg. Co.	70	6 mo.		12 % Wear Gradation		As. Con.	As. Con.
Ohio.	70			12 % Wear		Bit. Mac. As. Con.	Sheet A.
Ky.	75			10 % Wear	Bit. M.	Bit. Mac.	R. Asph. Sheet A.
Ga.	70	6 mo.	1.5 %	Coef. 5.5	R. Asp.	Bit. Mac.	As. Con.
W. Va.	70			15 % Wear		Bit. Mac.	
Miss.	70			Coef. 5		As. Con.	
Ala.	75	6 mo.	1.5 %	Coef. 5		Bit. Mac.	
A. S. T. M.	70				As. Con.	Bit. Mac.	
	65				Bit. M.	Asp. Con.	
Fed. Bd.	70	6 mo.			As. Con.	Bit. Mac.	
(Subject to change)						As. Con.	

TABLE VII
LIMITATIONS ON SLAG AS AGGREGATE IN MACADAM
CONSTRUCTION AS OF JANUARY 1st, 1926

State	Weight	Age	Sulphur	Physical Limit	Base	Wear	Struct.
Ohio (b).....	65	.....	.....	Soundness 15 % Wear.	.....	Macadam	
Ohio (c).....				Soundness 20 % Wear.	Mac.		
W. Va.....	70	6 mo.	.....	Soundness. 15 % Wear	.....	Macadam.	
Ky.....	75	.....	.....	10 % Wear	Mac.	Macadam.	
N. Car.....	75	.....	.....	.....	Mac.		
Va.....	65	.....	.....	5 Tough. 15 % Wear.	Mac.		
Mich.*.....				Coef. 6	Mac.		
Ala.....	75	.....	.....	Coef. 5	Mac.		
Pa.....	70	6 mo.	.....	.....	Mac.		
Ga.....	70	6 mo.	1.5 %	Coef. 5.5	Mac.	Macadam	
Fla.....	75	6 mo.	1.5 %	Coef. 4	Mac.	Macadam	
Bur. Rds.....	70	6 mo.*	*	.....	Mac.	Macadam	
A. S. T. M.....				12 % Wear	Mac.	Macadam	
Fed. Bd.....	70	6 mo.*	*	.....	Mac.	Macadam	
(Subject to change)							
Allegheny- Co. Pa.....	70	6 mo.	.....	12 % Wear Gradation	Mac.		

*Michigan—5 % by weight, objectionable matter.

**— or less if suitable.



Slag Concrete Highway between Cleveland and Youngstown, Ohio, built 1912-13.
 When inspected by the writer, May 24th, 1926, the surface was showing
 but slight wear and the maintenance cost had been very low.

CHAPTER II

TESTS ON BLAST FURNACE SLAG—THEIR INTERPRETATIONS AND CONCLUSIONS

In the following pages is given the results of a careful study of about fifty tests of various kinds on blast furnace slag. These tests have been studied, summarized, contracted, rearranged, and elaborated on; their values checked, combined, cross referenced, and some recomputed; and recommendations have been suggested, and some conclusions drawn. Reports from expert engineers on field observations where slag was used in highway construction are also included. A study of these tests and their value should throw some new light on the subject, especially to those engineers who have not used slag in highway construction, or who are skeptical about its use. These tests clearly indicate that air-cooled blast furnace slag is one of the best aggregates for all types of highway construction, and that the failure to utilize it when available or when other materials are transported from a greater distance to serve a purpose for which slag actually serves better is an economic waste of an excellent material. The tests, their interpretation, and conclusions follow.

An abstract from field inspection report on forty-one Ohio and twenty-seven Pennsylvania highways made by Fred Hubbard, Consulting Engineer, Standard Slag Company, of a field report by Professor Arthur H. Blanchard, Professor of Highway Engineering and Highway Transport, University of Michigan, reveals that blast furnace slag was used extensively in the highways inspected. Professor Blanchard states:

"An outstanding impression received as the result of the comprehensive inspection was a revelation of the extensive utilization of slags in the construction of various types of roads and pavements by highway departments. Ample evidence was furnished by the roads and pavements inspected that high grade bituminous surface treated slag roads, bituminous slag macadam pavements, bituminous slag concrete pavements, cement slag concrete pavements and durable slag foundations have been and can be constructed."

Numerous testimonials by Engineers prominent in the Highway profession can be cited showing the utility, perfect adaptability, and longevity of blast furnace slag when used in road construction both here and in Europe.

The writer recently made an inspection of a slag road in Missouri which has been in continuous use for nearly a century.

The Meramec Spring Road in Phelps County, Missouri, near St. James, 17 miles east of Rolla, and 100 miles southwest of St. Louis.

The Springs has a national reputation of being one of the largest springs in the world, and is one of the many beauty spots so abundant in the Ozarks. Here an old iron furnace functioned before and during the Civil War, and here also, using the ample water power contiguous, all of the milling for miles around was done.



A section of the Slag road in Phelps County, Missouri, which was built before the Civil War. It is still in excellent condition, though no repairs have been made since it was built.

Thomas James, of Ohio, came out prospecting for iron in 1825, and finding at Meramec Spring a good bank of iron and facilities for furnace operation, sent out his foreman, Benjamin Massey, to open up the works. Massey was made part owner. James' sons came out and had charge of the different departments. In 1866, William James became sole owner of the works. The business flourished until the business depression of 1873 set in, and then, on account of the process



The Meramec Blast Furnace in Phelps County, Missouri, the Slag from which was used in Highway Construction.

and other reasons, Mr. James failed and the works were closed for the first time in about a half century. The beautiful picturesque surroundings of the magnificent fountain, with its silent and massive furnaces, still remain. There were about 300 furnacemen, forgers, helpers, teamsters, miners, colliers, and woodchoppers employed to carry on the works.



A RECENT VIEW OF THE SLAG ROAD IN PHELPS COUNTY,
MISSOURI, WHICH WAS BUILT BEFORE THE CIVIL WAR

During the early operations of the furnace, a slag road was constructed, which is today in good shape; and as far as can be learned no repairs have ever been made on the portions of the road where slag was used. This road has always been in constant use as it affords the only outlet for a considerable scope of country hemmed in on one side by the Meramec River and on the other by numerous dissected, rather impassable rocky ridges. Consequently, all hauling has to be done over it; and now there is scarcely a day passing in the spring, summer, and fall without from 100 to 300 automobiles carrying visitors over it to the Spring. It is a common occurrence to see from 100 to 200 cars at the Spring at one time. During the winter cars are not so common, but throughout the entire year there is tie hauling over it, and farmers' wagons and cattle are continually being driven over this road. It is still in excellent condition, and for years has been one of the best roads in Phelps County.

In the following pages are given a number of comparative tests of blast furnace slag to show its adaptability as an aggregate in highway construction.

Footnote: The fifty tests on Blast Furnace Slag mentioned in the Preface are omitted in this Abstract. Copies of the full report are on file in the office of the Graduate School, and Davis Library of Highway Engineering of the University of Michigan, as well as at the office of the National Slag Association at Cleveland, Ohio.

CHAPTER III

CONCLUSIONS AND RECOMMENDATIONS

It has been the privilege and endeavor of the present recipient of the National Slag Association Fellowship in Highway Engineering to review the whole field of blast furnace slag and its utilization in highway construction, as well as in many of its other uses. This research has involved the unearthing of all the available writings on this important, though generally little known or understood, construction material. The undertaking has reached a magnitude undreamed of at its inception. It is well that the author has made this extensive study in the documentary evidence of the slag industry: It has shown him that the field is almost unlimited and provides ample opportunity for further needed specialized investigation.

To accomplish the task of finding the role slag should play as a mineral aggregate in highway construction, tests and observations of reputable and recognized engineers were studied and conclusions were drawn per se from their investigations. Some half hundred unbiased laboratory and field tests on blast furnace slag have been carefully studied

The general conclusions reached are as follows:

It is evident that highway laboratory investigation tests although developed through the collective and best thought of the testing engineers of America and abroad, are not exact. At best they give us only relative measures of the degree of permanence a material will have in actual service.

It is not so certain that some of the standard laboratory tests for rock, when applied to slag, even give a relative measure of the serviceability of slag, though they measure the properties of rock, for which they were designed, very well.

Records show that blast furnace slag has been used successfully in the following types of highway and street construction and no records could be found indicating a single failure traceable to the slag: Water-bound macadam, bituminous bound macadam, bituminous concrete, sheet asphalt, in bases for all types of surfaces, and in reinforced portland cement concrete. Service observation on these pavements range from one to fifteen years.

Blast furnace slag concrete has been used in numerous highway structures as well: as culverts, bridges, retaining walls, guard rails, etc., without a single record being found of a registered failure.

The various physical properties of slag when a great number of specimens were considered varied in merit directly as the apparent specific gravity.

Although the above conclusion is true, individual tests will vary widely from the norm.

Tests by the Bureau of Roads and by others show the Talbot-Jones depth of wear to be between a half and three-quarters of an inch. The wearing ability of slag compares favorably with that of any other highway construction material.

The Deval abrasion test does not seem to be a true indication of the value of slag as a road building material.

The Deval test for stone which was designed for determining resistance to wear for that material, seems to be fulfilling the expectations of its originator. However, blast furnace slags tested in the same machine receive punishment that is much out of proportion to what can be proven is obtained in actual highway service when that material is a component part of a wearing surface. It is practically impossible to establish a ratio between the figures represented by stone tested in the Deval machine and on slags tested in the same manner.

For the most part engineering groups who are developing and presenting specifications covering highway construction materials have for the past few years been revising their specifications and almost without exception have dropped the "Loss by abrasion" requirement on slag and retained the "Weight per unit volume" requirement. This statement applies to such groups as the American Society for Testing Materials, the American Concrete Institute, and the Federal Specifications Board.

The circular track wear tests of the Bureau of Roads showed commercial blast furnace slag to have as little wear as did any other aggregate.

It is recommended that blast furnace slag when measured loose should weigh at least 65 pounds per cubic foot.

The presence of large amounts of light, porous fragments will cause excessive wear.

Somewhat better results are secured by the use of the smaller sizes of slag.

In compression, for like mixes, slag concrete is invariably stronger than concrete made with any other aggregate at all ages tested up to five years.

Slag has never been known to slake on the job or in any concrete. Slags that have reached atmospheric temperature do not change further physically.

Not a single instance is cited, in the numerous tests and observations made, where slag in concrete has been known to corrode reinforcing steel when the steel has been properly covered and protected from the atmosphere, but on the other hand slag has been known to actually prevent steel from rusting.

The chemical and mineralogical composition of all slags is practically the same qualitatively, but of course not quantitatively.

Although one would conjecture that the quantitative chemical and mineralogical composition of slags should be reflected in certain physical properties, there is no evidence to prove it.

Slags having the range in chemical composition shown in the Table III, page 12, have proved satisfactory in highway construction. These include every commercial blast furnace slag.

Slags vary widely in physical properties; even slags from the same furnace. Further investigation is needed to ascertain the reason for this variation. Is it due to quantitative chemical make-up, to cooling, to crushing, to sampling, or to some other influence? Every characteristic must have a scientific explanation.

Freezing and thawing tests of specimens of blast furnace slag 25 times repeated apparently indicate that, though a unit volume of well graded slag has a relatively high percentage of voids, and though the material is capable of absorbing considerable water, it shows no signs of sprawling or disintegration due to excessive stresses.

All tests showed blast furnace slag to stand the sodium sulphate test for soundness.

Slag concrete withstands the action of acids better than does crushed stone samples.

Changes in moisture or temperature have produced no more appreciable cracks in slag concrete than in concrete where other aggregates have been used.

Although slag possesses a greater cementation tendency than other aggregates, it must be borne in mind that this cementing is slow in comparison with this property in portland cement, and it is not at all uniform, but where the process occurs it is a decided advantage to slag.

The results of physical tests on slag concrete are comparable only when the mixes are kept the same, the cement-water ratio or slump recorded, sizes of material noted, and sufficient control tests made.

The few tests made seem to indicate that basic open hearth and smelter slags have more nearly the properties of the common rocks than have any other slags, and they also have a higher specific gravity, are less glassy, and the standard physical tests fit them more consistently. Of course the advantage of lightness is lost. These slags are not generally commercialized but offer a field for speculation.

Tests show slag to be chemically pure. No chemical tests seem to indicate that slag pits contain refuse from the furnace as some engineers are wont to believe.

Slag is much lighter than stone, and has greater bulk to the ton, and so will have smaller freight charges per mile of road than will stone aggregates.

Over two hundred physical tests on blast furnace slag show the average physical properties to be as follows; Apparent specific gravity, 2.29; Absorption, 5.25; Slaking, O. K., Cementing value, 60; Hardness, 14.8; Toughness, 7.1; Deval Abrasion per cent 12.07; and French Coefficient, 4.31. These values, however, really mean little in comparing individual slag samples.

Its roughness of surface gives slag greater bonding power in cement concrete, in bituminous concrete, and in macadam road construction than other materials have.

Slag has no cleavage directions and will not split, as most all stone will.

Slag is a fireproof resisting material.

The age of slag seems to make no difference in its behavior in the tests or on the job.

Magnesia in slag is beneficial as far as the limits of chemical constituents affect slacking.

It is found in practice that when a construction gang learns to handle blast furnace slag, this material can be worked as well in concrete as any other aggregate and it gives as smooth a finish.

Slag concrete shows greater elasticity and resistance to impact than does gravel or stone concrete.

The transverse test shows slag beams to be generally stronger than gravel concrete beams.

There are some improvements needed in processing at a few of the plants before a perfectly satisfactory slag is produced. Such undesirable elements as coke and flux stone must be eliminated; also more care must be taken in sizing the product so that it can be supplied as specified.

RECOMMENDATIONS

Now that the general field of tests on blast furnace slag have been reviewed, certain further investigations recommend themselves.

Further Investigations Recommended:

1. Determine the expansion and shrinkage of concrete during moisture and temperature changes or both.
2. Determine the modulus of rupture of slag concrete of different proportions at different ages.
3. Determine the effect of repeated loading on dry and wet slag concrete.
4. Determine the direct tensile value of slag concrete from a period when it is only 24 hours old up to one year.
5. The same data should be ascertained for a comparative material.
6. Control tests should be run on all aggregates as well as on the cement.
7. Develop a soundness test for slag or determine whether such a test is feasible or desirable.
8. Investigate the possibility of a flotation test of some kind which would eliminate light pieces of some slag.
9. Slag concrete roads already built should be studied: diamond drill cores cut from such pavements should be tested at the laboratory; wear of pavement recorded; and other observations made. The complete history of the pavement should be ascertained at the time.
10. Various chemical combinations by cut and try might be resorted to at the pit while the slag is still molten, and their effects on the physical properties investigated.
11. Five-by-eight by eight-inch brick might be cast at furnace and tested in the Talbot-Jones Rattler.

12. A valuable bit of research would be to attempt to establish a relation between the quantitative chemical constitution of slag and its physical properties. In fact little advance in the present knowledge of the material is possible until work along this line is done.

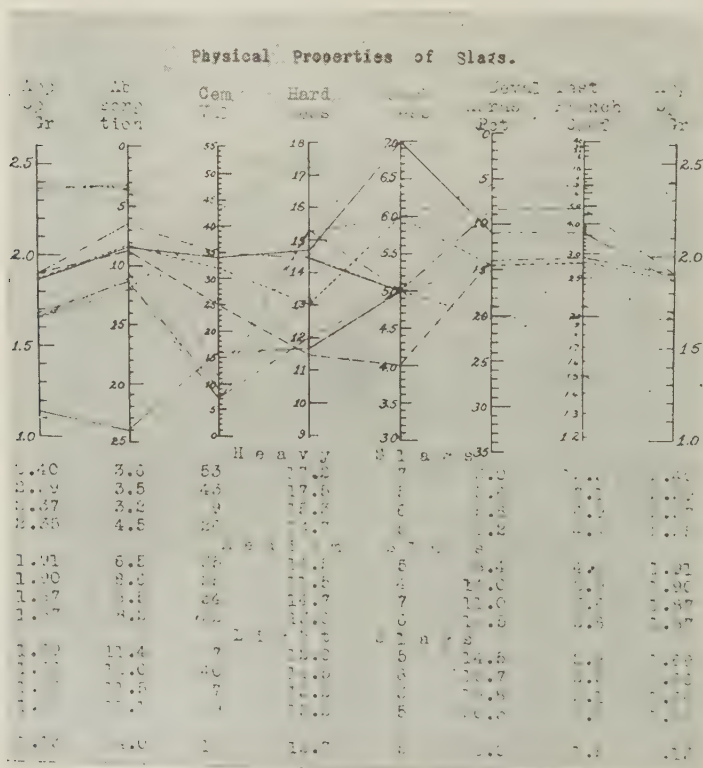
13. Tests should be made on mixtures of bituminous materials commonly used in highway construction and maintenance in which slag is the mineral aggregate.

14. Certain specimens of slag should be ground and the particles exposed to the action of the weather, so as to determine the corrosion.

15. Tests on slags of different ages and tests on slag used in different concrete mixes might well be made, both series to be accompanied by the other laboratory control tests.

16. A very instructive series of tests could be run on the bond strength of slag concrete in comparison with other materials, using different mixtures and sizes and at various ages. Little has been done along this line with American blast furnace slags.

17. Permanency tests of slag when used as a mineral aggregate in highway construction and maintenance might well be justified.



Physical Properties of Slags

CHART 9

18. A more comprehensive check on several investigators' work with slag that indicates small sized large aggregate in portland cement concrete apparently produced stronger concrete in the same mixes than does the larger sized material, controverting the axiomatic "The larger the stone, the stronger the concrete" of so many test book writers.

19. The smaller sized slag apparently finishes better in highway construction than do the larger sizes. Does it make for longer life? Or greater resistance to wear?

20. More investigation is needed on the coefficient of expansion of slag concrete. Do slag concrete highways really crack less than those made with competitive materials?

21. More general knowledge of the qualities of slag sand should be obtained in order to determine the limitations necessary to produce a satisfactory concrete aggregate, to determine a better binding and filling material, and to determine its utility in rolled base. It should be ascertained whether its successful use is a matter of technique during construction or whether it is a producing plant problem.

22. It is true that abundant knowledge is now available to demonstrate the superior compression strength of blast furnace slag; but it is desirable that this compression test be continued with each series of tests for the purpose of control. In addition to compression, the modulus of elasticity should also be obtained.

The following tabulation compiled by the Author from all sources available to him will indicate the number and nature of the tests made on blast furnace slag up to the present time.

TABLE VIII

SYMPOSIUM OF TESTS ON BLAST FURNACE SLAG

<i>Name of Test</i>	<i>No. of Tests</i>
Absorption	115
Apparent Specific Gravity	115
Action of Acids on Slag	1
Acid Slag vs. Basic Slag	1
Ageing of Slag	1
Bond between Concrete and Steel	5
Brittleness of Slag	1
Chemical Analysis	10
Compression	35
Circular Track	2
Comparison of Slag with other Materials	22
Corrosion of Steel by Sulphur	7
Cracking of Slag Concrete Highways	1
Calcium Chloride Accelerator Test	2
Cement-water ratio consideration	8
Curing conditions	8
Cost of Slag Concrete in Comparison	2
Control of Light and Porous Slags	2
Change in Volume	1
Cementing Value	100

<i>Name of Test</i>	<i>No. of Tests</i>
Chemical action of set of slag in concrete.....	1
Deval Test.....	100
Discoloration.....	2
Effect of prewetting slag before mixing.....	1
Effect of Temperature and Moisture Changes.....	4
Effect of variation in mix.....	21
Effect of size of material.....	17
Effect of Oil.....	1
Effect of Sulphate-bearing Waters.....	1
Elongation of Specimen.....	1
Evaporation.....	1
Effect of Shock and Impact.....	1
Fire Resistance.....	4
Fineness modulus consideration.....	7
Flow Table.....	5
Grading of Aggregate.....	9
Hardness.....	100
Increase in mortar content when slag is used.....	1
Mechanical or screen analysis.....	16
Modulus of Elasticity of Slag concrete in Compression.....	5
Modulus of Rupture.....	1
Normal Consistency.....	2
Phenomena of Dusting.....	2
Permanence, durability of slag concrete.....	1
Quality of Slag.....	4
Richness of mix.....	2
Relation of sound and crumbling slags.....	2
Rejection of flat and elongated pieces.....	2
Shrinkage, Contraction.....	2
Steam Test for Soundness.....	2
Sodium sulphate test for soundness.....	2
Slag as fine aggregate.....	5
Slump Test.....	4
Separation of slag into specific gravity classes.....	2
Surface Modulus.....	2
Talbot-Jones Rattler.....	8
Time of set of slag concrete.....	4
Tensile strength of slag sand.....	9
Test for voids.....	6
Test for maximum density of mortar.....	4
Transverse Test.....	3
Toughness.....	100
Variability of Slag.....	2
Weight per cubic foot.....	150
Workability of slag concrete.....	5
Weathering qualities of slag.....	1
Water tightness, permeability of slag concrete.....	1
Yield of Slag Concrete.....	3

The above tabulation may serve as an aid in ascertaining what tests are most needed in further investigations on blast furnace slag.



PLATE XVIII Slag Concrete Highway between Cleveland and Youngstown, Ohio, built 1912-13. When inspected by the writer, May 24, 1926, the surface was showing but slight wear and the maintenance cost had been very low.

APPENDIX A

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245. Stead, J. E. Blast Furnace Slag in Concrete and Reinforced Concrete. Engineering World, Vol. 14, pages 36 to 38, February 15, 1919; Vol. 14, pages 25 to 27, March 15, 1919. London Engineering, 1919.
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247. Stull, John W. Crushed Limestone vs. Slag for Concrete Aggregate. Rock Products, April 5, 1924, page 58.
An article upholding the virtues of crushed limestone and showing the inconsistencies of slag.
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- Reports observations made while having a slag with BaO in it, suggesting experimental investigation. 600 w.
249. Talbot, F. A. The Colloseus Process for Making Slag Cement. *Engineering and Mining Journal*, September 24, 1910.
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 250. Tomlin, Robert K. Jr. British and French Methods of Road Making. *Engineering News-Record*, January 31, 1918.
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Illustrated. Manufacture and Uses of Slag; U. S. Bureau of Roads Experiments Reviewed; Comparison with Portland Cement.
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Story of immense utilization of slag from basic Bessemer as phosphate fertilizer and of changes made necessary by alterations in technology of steel.
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Wear, compression, and nine-year service tests on concretes, various aggregates, slag being one. Impression of leaf in concrete pavement after nine years, indicating no appreciable wear.
 254. Waterhouse, G. B. Blast Furnace Slag. Economics in the Manufacture of Iron and Steel. *Engineering Magazine*, June, 1909.
The second of two articles dealing with the two great economies. The present number considers the utilization of blast-furnace slag, especially in the manufacture of cement. Ills. 4000 w.
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 256. Wennerstroem, H. G. Cement Production from Slag in Electric Furnaces. Swedish Development of Commercial Import-ance. *Rock Products*, August 13, 1921; *Tonindustrie-Zeitung*, March 17, 1921.
 257. Whitehead, C. K. Cement Mortars and Concrete, Use in. Comparative Tests of Slag with Pittsburg Sand and Gravel. *Pit and Quarry*, Vol. 9, No. 2, October 15, 1924, pages 95-101.
Describes tests made of fine and coarse aggregate for cement mortars and concrete, also similar tests made simultaneously with local sands and gravel.

258. Winters, O. C. Standard Slag Company of Youngstown, Ohio, Builds Its Seventeenth Crushing Plant. *Rock Products*, May 30, 1925.

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259. Wright, Clarence E. Slag Market. Widening Demand for Blast Furnace Slag. *Iron Age*, Vol. 103, No. 4, January 23, 1919, pages 241-243, 5 figs.

Uses to which it has been put; a possible \$20,000,000 income to industry.

260. Youngstown, Ohio, The Youngstown, Ohio, Slag Road. *Municipal Engineering*, February, 1912.

Information concerning the construction and results with this material as used on an experimental road built in 1909. 2500 w.

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262. Abrams, Duff A. Effect of Hydrated Lime and Other Powdered Admixtures in Concrete. *Proc. A. S. T. M.* Vol. XX, Part 2, 1920.

With appendix on further tests of hydrated lime in concrete.

263. Abrams, Duff A. Wear Tests of Concrete. *Proc. American Society for Testing Materials*, Vol. 21, 1921; *Bulletin No. 10*, Structural Materials Research Laboratory, Lewis Institute, Chicago.

264. Abrams, Duff A. A Method of Making Wear Tests on Concrete. *American Society for Testing Materials*, Vol. XVI, Part II, 1916.

Also Effect of Curing Condition on the Wear and Strength of Concrete, *Proc., American Railway Engineering Association*, Vol. 20, 1919; *Bulletin No. 2*, Lewis Institute, Chicago.

265. American Concrete Institute *Proc.*, Vol. 15, 1919. Proposed Standard Building Regulations for the Use of Reinforced Concrete.

266. American Concrete Institute *Proc.*, Vol. XV, 1919. Report of Committee on Sidewalks and Floors.

267. American Society for Testing Materials. Concrete and Concrete Aggregates, Tests and Specifications. Report of Committee C-9, 1923.

268. American Society for Testing Materials. Size of Slag Makes Little Variation in Its Weight. *Proc.*, Vol. 21, 1921, page 579—Standards.

269. American Society for Testing Materials Standards, 1923. Standard Specifications and Tests for Concrete and Concrete Aggregates.
270. American Society for Testing Materials Standards Issued Triennially, 1924. Blast Furnace Slag.
Standard Specifications and Tests for Concrete, page 633, Voids in Fine Aggregates for Concrete, page 761, Sieve Analysis of Aggregates for Concrete, page 767, Broken Slag for Waterbound Base and Wearing Course, page 919, Shovel-run or Crusher-run Broken Slag for Waterbound Base, page 921, Abrasion of Road Materials, page 923, App. Sp. Gr. of Sand, Stone and Slag Screenings, etc., page 928.
271. American Society for Testing Materials. Sulphur Limitations in Specifications of the A. S. T. M. Report of Committee C-9, June 29, 1923. Corrosion and bond strength.
272. American Society for Testing Materials. Road and Paving Materials. Report of Committee D-4, 1923, Tentative Specifications.
273. American Society for Testing Materials Standards Revised to 1923. Tentative Specifications for Slag in Every Type of Modern Road Construction.
274. Bernays, Edwin Arthur. Portland Cement Concrete and Some of Its Applications. Paper No. 1689, Minutes of Proc Institute of Civil Engineers, Vol. LXII, pages 87-97.
History on first uses of concrete.
275. Chapman, Cloyd M. Influence of Aggregates Upon Shrinkage of Mortar and Concrete. A. S. T. M. Proc., Vol. 24, Part II, 1924.
Discusses a floor that curled up into large saucers, and other contraction failures. Tests run on shrinkage of various mortars shows that when slag is used the mortar shrinks the least.
276. Fletcher, J. E. Blast-Furnace and Cupola Slags. Iron and Steel Institute, Annual Meeting May 5-6, 1921, advance paper No. 3, 20 pages, 12 figs. Also Eng. Vol. 111, No. 2894, June 17, 1921, pages 760-762, 12 figs.
Their composition and graphic methods for determining their constitution.
277. Freeman, P. J. Tests of Blast Furnace Slag as the Coarse Aggregate in Concrete. Proc. American Concrete Institute, Vol. 14, pages 95 to 100, 1918.
Gives results of compression tests on concrete made of slags from nine different sources, in comparison with six other aggregates. From tests up to one year, the slag concretes were superior to the other. Also superior to others in five-year tests. Tests made 1917 to 1921. Wt. per cu. ft., percentage of voids, sp. gr. and av. crushing strengths are given for 14, 30, 60, 180 days, 1, 2, 3, 4, and 5 years, complete analysis of fine aggregates, chemical analysis of slags,

and reinforcing steel for corrosion test. Relative standings of the nine slags. 4 charts. Description and conclusions. This paper gives the tests up to one year. Pittsburgh Testing Laboratory Report, 1921, gives the complete five-year tests.

278. Harsch, Raymond. Blast-Furnace Slag as an Aggregate in Concrete. American Society for Testing Materials, Advance Paper No. 40, for Meeting June 25-29, 1923, 20 pages, 2 figs.; A. S. T. M. Proc., Vol. 23, Part II, 1923, pages 255 to 273; Discussion pages 274 to 275. Report U. S. Dept. of Agriculture, U. S. Office of Public Roads, August 18, 1923.

Raymond Harsch tests run right into tests by Jackson Pauls, A. S. T. M. Proc., Vol. 24, Part II, 1924. Public Roads, May, 1924, pages 1-19. Address by Frederick Hubbard, Research Engineer, Standard Slag Co., Youngstown, Ohio, before Class in Highway Engineering, University of Michigan, January 8, 1926, pages 16-21. Methods used in production of slag, as found in investigation of over 30 commercial plants. Tests of slag made in 1919-1920 include sp. gr., absorption, deval, sodium sulphate, chemical analysis, Talbot-Jones Rattler, modulus of rupture, modulus of elasticity in compression and bending, and compression tests. Comparison with limestone and gravel.

279. Harsch, R. Blast-Furnace Slag as an Aggregate in Concrete. Am. Soc. Test. Mat. Proc. 23, pages 255-273; Discussion, pages 274-275, 1923.
280. Harsch, Raymond. Flow Sheet—Diagram of Typical Slag Crushing and Screening Plant. Proc. A. S. T. M., Vol. 23, Part II, 1923.

281. Howe, R. M. A Study of the Slag Test. American Ceramic Society Journal, Vol. 6, No. 2, Feb., 1923, pages 466-473.

Details of two tests made to study action of slag upon refractory materials; in one penetration of slag is measured by means of a planimeter, and in other its solvent action is determined by studying effect upon fusion points of fire brick.

282. Hull, W. A. Fire Tests of Concrete Columns. Proc. American Concrete Institute, Vol. 15, pages 89 to 107, 1919.

Among tests of various aggregates as to fire resistive properties, blast furnace slag makes favorable showing. Also report of the Committee on Fireproofing.

283. Johnson, J. E., Jr. The Effect of Alumina in Blast-Furnace Slags. Discussion of the Paper. Bulletin American Institute of Mining Engineers, December, 1912. 4000 w.

284. Joint Committee Report on Standard Specifications for Concrete and Reinforced Concrete. Bulletin, June 4, 1921. Affiliated Committees of the A. S. C. E.; A. S. T. M.; A. R. E. A.; A. C. I.; and P. C. A.

285. Kern, Edward F. The Reduction of Manganiferous Silicate Slags. General Meeting American Electrochemical Society, April 8 to 10, 1920, paper 15, pages 221-232.

Calculations are made of theoretical power needed for reduction and as sensible heat in products, and net thermal efficiency of electric-furnace operations is determined. Experiments are described in which percentages of manganese, silicon and iron reduced and escaping reduction were determined and also proportions volatilized.

286. Knight, Arthur. The Formation and Functions of Blast Furnace Slags. Birmingham Metallurgical Society Journal, Vol. 8, No. 6, 1923, pages 209-242, 4 figs.

Indicates how far knowledge accruing from scientific investigations can up to present time be applied to problems of actual practice; tables giving temperature-viscosity relations of various blast-furnace slags.

287. Lord, E. C. E. The Composition and Properties of Slag for Road Making. Paper of the U. S. Office of Public Roads presented at Third International Road Congress, May 27-29, 1909; Davis Library Reference No. 88 C.

Discusses relation of chemical and mineralogical properties to physical properties of slags; and discusses the slags desirable for highway construction.

288. Love, H. J. Blast Furnace Slag. Paper read before Meeting of Testing Engineers and Chemists of State Highway Departments at U. S. Office of Public Roads, Washington, D. C., on February 25, 1920.

General discussion on slag; water-bound macadam and bituminous macadam roads.

289. Love, H. J. Symposium: Limitation on Slag in Concrete and Reinforced Concrete as Imposed by Fifteen State Highway Departments.

U. S. O. P. R.; A. C. I.; and A. S. T. M., as published in Specifications of 1922 also for 1926.

290. Miller, Dalton G. Laboratory Investigations of the Influence of Curing Conditions and Various Admixtures on the Life of Concrete Stored in Sulfate Solutions as Indicated by Physical Changes. Proc. A. S. T. M., Vol. 24, Part II, 1924.

291. National Association of Cement Users. Meeting of Section on Floors, Sidewalks and Floors.

Proceedings on Floor of National Association of Cement Users, Vol. 3, 1907, page 168.

292. Norton, F. H. A Quantitative Laboratory Slag Test. American Society Journal, Vol. 7, No. 8, August, 1924, pages 599-602, 4 figs.

Describes laboratory test capable of giving quantitatively resistance of refractories to slags.

293. Royster, P. H., and T. L. Joseph. Effect of Coke Combustibility on Stock Descent in Blast Furnaces. American Institute of Mining and Metallurgical Engineers Trans., No. 1307 S, March, 1924, 10 pages, 3 figs.
- Stock descent in blast furnace is affected by size of combustion zone which varies inversely with coke combustibility; predominating tendency is for coke to feed downward into space where combustion is taking place; discusses three types of combustion.
291. Shinn, J. A. Blast Furnace Slag as a Structural Material. Proc. Engineers' Society of Western Pennsylvania, Vol. 20, pages 157 to 176, 1904.
- Reviews uses to which slag has been applied, and gives references to earlier tests and articles. And a good historical review of the industry up to 1904.
295. Sisco, F. T. Fluorine in the Deoxidizing Slag, and Its Influence on Refractories in Basic Electric Furnace Practice. American Electrochem. Society Trans., Vol. 46 (preprint 19) 257-72, October, 1924. Same cond., Iron Trade Review, 75:1305-7, November 13, 1924.
296. Specifications. Tentative Specifications and Building Codes, giving Limitations on Blast Furnace Slag. National Slag Association Symposium. 100 pages.
297. Stephens, A. W. Investigation Into the Economic Possibilities of Light Weight Aggregate in Building Construction. Paper Presented to Joint Session of A. S. T. M. and A. C. I. at Atlantic City, June 27, 1919.
298. Stineman, Norman M. High Point of the New Joint Committee on Concrete. Address before Eleventh Annual Meeting of the Building Officials Conference, April 21-24, 1925, at Madison, Wis. Also in Concrete, May, 1925, page 155.
299. Thompson, Sanford E. Concrete Aggregates. Proc. National Association of Cement Users, Vol. 2, 1906, pages 27-46. Paper with discussion.
300. Thompson, S. E. Slag as Concrete Aggregate. Proc. American Concrete Institute, Vol. 13, pages 107 to 116, 1917.
- Presents results of tests showing very high strength of slag concrete. No authentic cases of deterioration of slag concrete, or of rusting of steel embedded in such concrete. have been discovered. Conclusions.
301. Walker, Stanton. Modules of Elasticity of Concrete. Proc. American Society for Testing Materials, Vol. XIX, Part II, 1919. Bulletin No. 5, Lewis Institute, Chicago.

APPENDIX B

CHRONOLOGICAL BIBLIOGRAPHY ON BLAST FURNACE SLAG

(1927)*

- 1871 *Strength of Cement*, by John Grant.
Proceed., Inst. of Civil Engrs. (England) 1871. A paper on the early use of Portland cement concrete, with tables of test figures giving compression values. Slag was one of the aggregates used in the tests.
- 1879 *Portland Cement Concrete and Some of Its Applications*, by E. A. Bernays.
Proceed., Inst. of Civil Engrs. (England) 1879. References to the use of Slag concrete for facing seawalls occur in this paper on the early uses of Portland cement concrete. Methods of making concrete are discussed and suggestions made for their improvement.
- 1890 *Utilization of Slag*, by Gilbert Redgrave.
Engineering News, 3/1/90, page 211. A paper on the uses to which slag had been put in the United Kingdom at that time. The list includes blocks, bricks, cement, and slag wool. Its use as an antiseptic is also mentioned. Thomas slag was being used for fertilizer.
- 1891 *Streets and Highways in Foreign Countries*, by U. S. Department of State.
Book published by U. S. Dep't of State, 1891 on European methods of road-building. Slag is one of the materials of construction in Germany, England, Scotland, France, Holland and Austria, mostly in the form of blocks or bricks.
- 1896 *Recent Economics in Iron and Steel Manufacture*, by H. G. Graves (England).
Mineral Industry, page 379. The uses of slag in Germany, France and Britain, as a by-product of the iron and steel industry, include slag wool, cement, slag-lime brick, concrete, cast blocks, and as a material in the construction of highways. Conservation of the waste heat from slag is considered and the use of basic slag for fertilizer.
- 1900 *Compression Tests of Concrete Cubes for City of Cleveland*, by W. M. Kingsley.
Results of compression tests, the fine aggregate being slag dust and the coarse aggregate crushed slag.
- 1902 *Slag Cement Manufacture in Alabama*, by Edwin O. Eckel.
Engineering News, 1/23/02, page 62. An account of the manufacture of two brands of slag cement, made with powdered slaked lime and granulated slag. Chemical analyses of the cement are included.

*Through the courtesy of the National Slag Association, H. J. Love, Secretary-Treasurer, 933 Leader-News Building, Cleveland, Ohio.

- 1904 Blast Furnace Slag as a structural material, by Jos. A. Shinn, Engineers' Society of Western Pennsylvania, Proceedings, page 157. A paper in which the author goes back to the earliest uses of slag, in Europe, citing the use of brick, block, slag wool, cement, concrete and roads, in all of which slag was a component part.
- 1905 Calcareous Cements—Their Nature, Manufacture and Uses, by Gilbert R. Redgrave and Chas. Spackman.
A book published by Griffin and Co., London, England, in which the author treats of various cements, in some of which slag is an ingredient.
- 1905 Why Not Use Slag? by the Illinois Slag and Ballast Co., Chicago.
A booklet published by the authors, detailing the uses of slag in the vicinity of Chicago, as far back as 1879, as ballast, and in roads and concrete structures. Statements of men in other sections of the country are also cited to prove the desirability of using slag. (Out of print.)
- 1906 Concrete Aggregates, by Sanford E. Thompson.
A paper read before the National Association of Cement Users (Proceed., page 27) in which slag is listed both as fine and coarse aggregate.
- 1906 Testing of Building Materials by the Sand-blast Apparatus, by Prof. H. Burchartz (Germany).
Engineering (London), 11/30/06, page 717. An abrasion apparatus developed by the Germans, using a sand-blast. It is claimed by the author that this test is more representative than the grinding test or the rattler tests for abrasion. Slag samples showed an equal resistance with trap, and much greater resistance than limestone.
- 1907 Meeting of the Section on Streets and Sidewalks of the N. A. C. U.
The report of the meeting of this Committee of the National Association of Cement Users (Proceed., Vol. 3, page 168) advises the ageing of slag before using in sidewalks. Granulated slag is used as base.
- 1907 Comparative Tests of Slag and Sandstone as Aggregates, by H. J. Kesner and F. W. Doolittle.
A thesis, published in Mining Reporter, 7/18/07, page 54. It deals with tests of smelter slag in concrete, giving compressive and tensile strengths, modulus of rupture, and resistance to abrasion.
- 1908 Manufacture of Concrete Bricks from Blast Furnace Slag, by Josiah Butler (England).
Iron and Coal Trades Review, 1/24/09, page 324. Detailed account of the processing of a slag-lime brick manufactured in England, which reached a production of 45,000 bricks per day. They replace red brick, and have been used in chimney stacks, boiler settings and in dwelling

houses, with excellent results. A test in which the brick were alternately frozen and boiled showed no detrimental effect on the Slag-lime brick.

- 1908 Track Depression of the Seaboard Air Line Railway at Birmingham, Ala., by Philip Aylett.

Engineering News, 10/1/08, page 354.

Eleven thousand cubic yards of slag concrete were used in this underpass, and proved very satisfactory, both as to compression and tension.

- 1909 Composition and Properties of Slag for Roads, by E. C. E. Lord.

A paper on the petrographic composition of slag, with reference to its use in roads. Mellilite was decided to be the cementing factor in slag.

- 1909 Concrete Aggregates: Special Report of Interim Committee, by British Fire Prevention Committee.

Published in Surveyor and Municipal Engineer, 1/8/09. page 32. The Committee's report specified slag as suitable for use as concrete aggregate under fire-resisting conditions.

- 1909 Basic Slag Wanted by Consul-General Skinner, Hamburg, Germany.

An extract from the Daily Consular and Trade Reports, 3/30/09. There is a large market in Europe for basic slag from steel manufacture, for fertilizing purposes. A short account of its preparation for market is included.

- 1910 Blast Furnace Slag as Concrete Aggregate, by Dr. H. Passow, Hamburg, Germany.

Magazine article in Stahl und Eisen, 5/10, page 829. Tests of concrete in which slag was the coarse aggregate and of concrete in which slag cements were used. Compressive and tensile strengths are given. Granulated slag and slag screenings were also tried out as fine aggregate. (Out of print.)

- 1910 Cement from Blast Furnace Slags, by Consul-General John L. Griffiths, England.

An extract from the Daily Consular and Trade Reports, 10/17/10. It deals with the use of slag as one of the raw materials in the manufacture of cement in Germany and England; tensile and compressive strengths of test samples are given.

- 1911 Furnace Slags in Concrete, by Carnegie Steel Co.

A booklet published by the authors, in which tests are reported on slag concretes in which slag was both fine and coarse aggregate. Granulated slag and slag screenings were used for fine aggregate. Compressive strengths were the only indications of desirability considered in these tests. (Out of print.)

- 1911 Progress Reports of Experiments in Dust Prevention, by U. S. Bureau of Roads.
Circular 94 of the Department of Agriculture, giving the progress report on an experiment in dust prevention, in which slag was one of the materials used, in combination with coke-oven tar, sulphite liquor, etc. (May be obtained through Superintendent of Documents, Washington, D. C.)
- 1912 Progress Reports of Experiments in Dust Prevention, by U. S. Bureau of Roads.
Circular 98 of the Department of Agriculture, of the same nature as Circular 94 above, giving the progress report of 12/12/12.
- 1913 Comparative Tests of Stone and Slag Concrete, by Prof. R. H. Fernald, Case School, Cleveland.
Results of compression tests on concrete containing slag, stone and slag sand.
- 1913 Progress Report of Experiments in Dust Prevention, by U. S. Bureau of Roads.
Circular 99 of the Department of Agriculture, giving the progress report on experiments in dust prevention in which slag was one of the aggregates, in combination with coke-oven tar, sulphite liquor, etc. (May be obtained through Superintendent of Documents, Washington, D. C.)
- 1913 Manufacture of Paving Brick from Slag, by Frank G. Bolles, Commercial Agent.
Extract from Daily Consular and Trade Reports, 8/13/13, outlining the process of manufacture of slag paving brick in England.
- 1914 Blast Furnace Slag as an Aggregate in Concrete, by W. A. Aiken.
Concrete-Cement Age, 8/14, page 65. A. S. T. M. Proceed., 1914, page 280. Compressive strengths are reported on slag concretes, and the author's opinion on ageing of slag, and its desirability generally as a concrete aggregate.
- 1914 German Utilization of Slag, by Consul-General A. M. Thacker, Berlin, Germany.
Extract from Daily Consular and Trade Reports, 2/10/14, listing the uses to which slag is put in Germany. It included brick, block, tile and artificial pumice stone. It is used as a raw material in the manufacture of cement, and in glass-making; also in roads, and as ballast. Slag sand and granulated slag are used as fine aggregates, and crushed slag as coarse aggregate in concrete.
- 1914 Slag Industry in the South, by S. G. Reynolds.
Manufacturers' Record, 8/27/14, page 47. A review of the slag industry in the South, where slag is used in cements and in road-building. Note is also made of building construction using slag concrete, which proved almost impossible to raze, in spite of the use of dynamite. Foundation bolts

after 20 years in slag concrete were found to be in a state of absolute preservation.

- 1914 Progress Report of Experiments in Dust Prevention, by U. S. Bureau of Roads.

Circular 105 of Department of Agriculture—the progress report on experiments in dust prevention, using slag in combination with coke-oven tar, sulphite liquor, etc. (May be obtained through Superintendent of Documents, Washington, D. C.)

- 1914 Washed Gravel versus Limestone and Slag.

Concrete-Cement Age, 9/14, page 121. A discussion on this subject by various construction men. Limestone and slag are considered on a parity, and opinions differ as to the relative merits of gravel and the other aggregates. Mr. Carey of Cleveland favors slag very distinctly.

- 1914 Use of Blast Furnace Slag as a Concrete Aggregate.

Concrete-Cement Age, 12/14, page 247. Discussion on this subject by several concrete experts. The general opinion is decidedly in favor of slag, instances being cited where slag concrete has given excellent service.

- 1915 Slag for Building, by Standard Slag Co., Youngstown, O.

Booklet on the use of slag in concrete construction. Figures are given from tests for compressive strength, yield, bond and permeability. Instances of the use of slag concrete in construction are enumerated and pictures of such structures appear throughout the book. (Out of print.)

- 1915 Slag by Emanuel Slag Co., Catasauqua, Pa.

Booklet on the uses of slag—in roads, in concrete construction and concrete blocks. Compressive strength figures on slag concrete are also given. (Out of print.)

- 1915 Liming of Soils, by H. J. Wheeler.

Bulletin 77 of Department of Agriculture on liming of soils—basic slag meal is advised as one of the lime-bearing mediums. Blast furnace slag is not mentioned. (May be obtained from Superintendent of Documents, Washington, D. C.)

- 1915 Progress Report of Experiments in Dust Prevention, by U. S. Bureau of Roads.

Bulletin 257 of Department of Agriculture—the progress report on dust-prevention experiments, using slag in combination with coke-oven tar, sulphite liquor, etc. (May be obtained from Superintendent of Documents, Washington, D. C.)

1915. Tests of Slag for Sewage Disposal, by Edward Orton.

Results of freezing and thawing tests on slags intended for sewage-disposal beds. Acid tests were also conducted on the slags, the results in both cases being entirely satisfactory.

- 1915 Use of Slag as Aggregate in Concrete.

Concrete-Cement Age, 4/15, page 210. Discussion on this subject by several concrete experts, in which numerous instances are cited on the satisfactory service given by slag concrete. Note is made of one particularly tough section of slag concrete which it was almost impossible to remove when razing the building in question.

- 1915 Ornamental Bridge at Akron of Slag Concrete.

Engineering News, 10/21/15, page 769. An account of the construction of the North Howard St. viaduct at Akron, O., with photographs. This structure contains 5,000 cu. yds. of slag concrete.

- 1916 Concrete, Plain and Reinforced, by Frederick W. Taylor and Sanford E. Thompson.

Published by Wiley and Sons, New York City. Book on the principles of plain and reinforced concrete, in which slag is listed as one of the typical aggregates, and as one of the raw materials entering into the manufacture of Portland cement.

- 1916 Slag Concrete Stronger than Stone, by Engineering News Record.

Eng. News Record, 1/29/16, page 151. An account of tests for compression and modulus of elasticity figures on stone and slag concrete.

- 1916 Increasing Use of Slag Aggregate, by E. C. Brown.

Concrete, 7/17 page 20. Proceed. of Engineers' Society of Western Pa., 1915, page 884. One of the most exhaustive treatises on slag of which there is any record; deals with almost every phase of the uses of slag, with particular attention to concrete construction. Twenty-four sub-authors contribute their opinions on the use of slag, as discussion of the original paper.

- 1916 Results of Physical Tests of Rocks, by Frank Jackson and Prevost Hubbard.

Bulletin 370 of Department of Agriculture—tests run on abrasion, absorption, cementation, hardness and toughness of slags, both blast furnace and open-hearth. (May be obtained from Superintendent of Documents, Washington, D. C.)

- 1917 Specifications for Slag in Concrete, by Sanford E. Thompson.

Amer. Con. Inst. Proceed., Vol. 13, page 107. Specifications demanding a chemical limit and ageing qualification were advised at that time.

- 1917 Physical Properties of Slags, by A. S. Rea.

Data developed by Ohio State Highway Department on abrasion, cementation, absorption, hardness, toughness and specific gravity of slag.

- 1917 Macadam Road Construction, by Clyde J. Knisely.
Published by Heer Printing Co., Columbus, O. Book on the principles of macadam road construction, both bituminous and waterbound. Slag and limestone are the typical aggregates for construction and maintenance of this type of road. (Out of print.)
- 1917 Specifications for the Supply of Slag, by Dr. A. Guttman, Dusseldorf, Germany.
Stahl und Eisen, 1/17, page 546. A specification prepared in Germany for the use of slag, by a Joint Committee of German Iron Works, Public Works Department, and other interested bodies. The process of preparing the slag is given in considerable detail.
- 1917 Experiments with Slag No. 1, by Prof. H. Burchartz, Berlin, Germany.
Stahl und Eisen, 1917. The results of experiments on which were based specifications for slag. The experiments included weathering of slag samples in the open, storage of slag concrete in sea-water, and tests of iron Portland cement in sea-water concrete.
- 1917 Experiments with Blast Furnace Slag No. 3, by Prof. H. Burchartz, Berlin, Germany.
Stahl und Eisen, 1917. Further experiments on slag, on which to base specifications, as above. They comprise observation of weathering slag samples left in the open for five years, and of iron embedded in different concretes.
- 1917 Experiments with Blast Furnace Slag 3, by Prof. H. Burchartz, Berlin, Germany.
Stahl und Eisen, 1917. Further experiments of slag on which to base specifications, as above. They include observation of the density, permeability and absorption of slag concrete. Compressive and tensile strengths are also given for concretes in which iron Portland cement was used.
- 1917 Does Slag have a Corrosive Effect on Steel? by Jas. O. Handy.
Concrete 3/17, page 119. A consideration of the possibility of corrosive effect on steel, due to the use of slag in reinforced concrete.
- 1917 Roads and Pavements, by A. W. Bowles.
University of Texas Bulletin 1735, 6/20/17. Slag is one of the typical concrete aggregates mentioned for use in Texas roads.
- 1917 Toughness of Bituminous Aggregates, by Chas. S. Reeve and Richard H. Lewis.
Journal of Agricultural Research, Vol. 10, 8/13/17, page 319. Test figures on slag in bituminous mixtures, with especial reference to toughness. (May be obtained from Superintendent of Documents, Washington, D. C.)

- 1917 German Activities in Iron and Steel Industry.
Blast Furnace and Steel Plant, 9/17. The Royal Institute of Tests and Materials (German) passes favorably on the use of slag in concrete, on an equal basis with other aggregates.
- 1917 Standard Forms for Specifications, Tests and Sampling, by U. S. Bureau of Roads.
Bulletin 555 of Department of Agriculture, 11/26/17. Suggested forms for specifications, and for sampling and tests of materials. (May be obtained from the Superintendent of Documents, Washington, D. C.)
- 1917 Tests of Concrete Aggregates Used in Texas, by J. P. Nash.
University of Texas Bulletin 1771, 12/20/17. Abrasion tests on concrete cylinders, run in a rattler with shot rolling in the cylinders. Compression and absorption tests were run on the specimens after the rattler test. (May be obtained from the University of Texas.)
- 1917 Slag as a Concrete Aggregate, by Sanford E. Thompson.
Amer. Con. Institute, Vol. 13, page 107. Results of tests on slag concrete to determine its suitability. They included compression, tensile, modulus of elasticity, and absorption. The chemical composition, ageing, durability and workability were also considered.
- 1918 Materials for Road Construction.
Proceedings, Amer. Society of Civil Engineers, pages 1400, 1420, 1427, 1918. In this report of the Road Materials Committee, slag is defined as road-metal and as a concrete aggregate, and recommended in the construction of bituminous concrete.
- 1918 Tests of Slag, Stone and Gravel Aggregate, by P. H. Freeman.
Amer. Con. Institute, Vol. 14, page 95. Compressive strength figures on concretes up to one year of age.
- 1918 Tests of Slag as Concrete Aggregate, by P. J. Freeman.
Amer. Con. Institute, Vol. 14, page 95. Compressive strength figures on concretes up to five years of age, with gravel, stone and slag as aggregates.
- 1918 Tests of Slag as Aggregate in Concrete, by P. J. Freeman.
Tabulated compression data from preceding.
- 1918 Recommended Practice for Concrete Road Construction, by the Committee on Roads and Pavements of the A. C. I.
Amer. Con. Institute, Vol. 14, page 519. Slag is not mentioned as one of the aggregates, except by inference, when it is stated that the slotted Deval cylinder eliminates the dust cushion in the abrasion test, with good results in the testing of slags and pebbles.
- 1918 Slag for European Roadmaking, by A. M. Thackara, Paris, France.
American Consulate-General, 1918. Statements of the use of slag in European roads for thirty years back, with good results.

- 1918 Tentative Constitution of the National Slag Association.
Membership, Officers, Executive Committee, etc., of
the National Slag Association, 933 Leader Building, Cleve-
land, O.
- 1918 Laws Governing Philadelphia Building Construction, by City
of Philadelphia.
Philadelphia building regulations in which slag is in-
cluded.
- 1918 British and French Road Methods, by Robt. K. Tomlin.
Eng. News Record, 1/13/18, page 198. The statement
of a French engineer on the use of slag macadam construction
at the Front in France.
- 1918 Effect of Slag on Setting of Portland Cement, by E. Denny
and E. H. Lewis.
Chemical News, Vol. 117, 2/22/18. The effect of the
addition of granulated slag to the raw cement clinker, on
tensile and compressive strength
- 1918 Progress Report of Experiments in Dust Prevention, by U. S.
Bureau of Roads..
Bulletin 586 of Department of Agriculture, 2/28/1.
The progress report of experiments in dust prevention in,
which slag was used in combination with coke-oven tar,
sulphite liquor, etc. (May be obtained from Superintendent
of Documents, Washington, D. C.)
- 1918 Public Roads, by U. S. Bureau of Roads.
- 1920 Public Roads, 5/18 to 1/20.
A bound volume of the monthly magazines of "Public
Roads," containing several articles on the uses of slag in
bituminous construction, concrete pavements and in rolled
base under brick. (May be obtained from Superintendent
of Documents, Washington, D. C.)
- 1918 Slag Makes Light and Strong Concrete, by Prof. Curtis C.
Myers.
Eng. News Records, 5/16/18, page 956. Tests on slag
concrete for compression, tensile, elasticity, bond, impact
and rupture.
- 1918 Results of Physical Tests of Rocks, by Prevost Hubbard and
Frank H. Jackson.
Bulletin 670 of Department of Agriculture, 6/14/18.
Results of tests on blast-furnace, smelter and open-hearth
slags, for abrasion, absorption, cementation, hardness and
toughness. (May be obtained from the Superintendent of
Documents, Washington, D. C.)
- 1918 Correspondence on Brick Moulds, by C. L. Stiff and Co.,
Irlam, England.
Correspondence relating to the handling of slag at the
furnace, and the manufacture of slag bricks by pouring into
moulds while liquid.

- 1918 Correspondence with War Industries Board on Slag, by National Slag Association.
Correspondence, 7/5/18, on the production, disposal and use of slag.
- 1918 Slag as Aggregate for Concrete Ships, by Prof. Curtis C. Myers.
Iron Age, 7/18/18, page 152. Data on tests of slag concrete for bond, compression, impact, rupture and tensile strength.
- 1918 Typical Specifications for Non-bituminous Road Materials, by Provost Hubbard and Frank H. Jackson.
Bulletin 704 of the Department of Agriculture, 8/30/18.
In these specifications, slag is allowed only in macadam construction. (May be obtained from Superintendent of Documents, Washington, D. C.)
- 1918 Slag Concrete Used to Complete Georgia Road Contract, by Concrete Highway Magazine, 10/18.
Concrete pavement in Georgia finished with slag when the supply of stone became depleted. Results very satisfactory. (May be obtained from Portland Cement Association, Chicago, Ill.)
- 1918 Brick Moulds Correspondence, by Teasdale Bros., Darlington, England.
Correspondence on moulds for use in manufacturing poured slag bricks in England, with additional information on instances of American use of English slag brick for paving.
- 1918 Correspondence re Lightweight Aggregate for Concrete Ships, by H. M. Chanee.
Correspondence on the possibilities of mechanical separation of slag into heavy and light particles, and the uses to which these two grades could be put.
- 1918 Correspondence re Stability of Slags, by E. C. E. Lord.
Correspondence on the stability of slag, and the necessity of allowing it to age, in order to insure against crumbling. The opinion is ventured that chemical composition is the criterion by which the stability of a slag can be ascertained.
- 1919 Highway Inspectors' Handbook, by Prevost Hubbard.
Book published by Wiley and Sons, New York City.
Instructions to inspectors on different types of bituminous construction, with specifications for each type. Slag is considered satisfactory in every type.
- 1919 Building Regulations for Reinforced Concrete, by Committee on Reinforced Concrete and Building Laws of the A. C. I.
Amer. Con. Institute, Vol. 15, page 387. Slag included in these specifications.
- 1919 Fire Tests of Concrete Columns, by Walter A. Hull.
Amer. Con. Institute, Vol. 15, page 89. Tests of concretes, of which slag was one, for fire-resisting qualities.

Specimens were in the form of columns, and were tested at the Pittsburg laboratory of the U. S. Bureau of Standards. Compression tests were run on the columns after the fire test.

- 1919 Report of Committee on Concrete Sidewalks and Floors, of the A. C. I.

Amer. Con. Institute, Vol. 15, page 411. Specifications developed by this Committee included slag as one of the aggregates.

- 1919 Modulus of Elasticity of Concrete, by Stanton Walker.

A. S. T. M., Vol. 19, page 510. Bulletin 5 of Structural Materials Research Laboratory, Portland Cement Association. Tests for modulus of elasticity of concretes—compression strengths were also obtained. (May be obtained from Portland Cement Association, Chicago.)

- 1919 Use of Slag in the Building Industry, by Dr. A. Guttman, Dusseldorf, Germany.

Published by Association of German Iron Smelters. The most exhaustive thesis ever prepared on the production, disposal, processing and uses of slag in Europe. Tests were run for every requirement—compressive, tensile, elasticity, etc. Mention of every known use of slag is made—roads, buildings, cement, etc.

- 1919 Cost and Value of a Good Highway, by John F. Gallier.

An article on the resurfacing of an old road with 3" of bituminous slag mixture, and the figures on its maintenance costs over a period of 18 years.

- 1919 Cleveland's Building Code for Reinforced Concrete, by City of Cleveland.

These specifications include slag as one of the aggregates.

- 1919 Blast Furnace Slag in Plain and Reinforced Concrete, by Dr. J. E. Stead, England Engineering World, 2/19.

The corrosive qualities of slag in reinforced concrete are considered, and the decision is reached that no such effect is evident. Slag concrete in sea water, and the ageing of slags on the dump, are given attention.

- 1919 Some Points on Finishing Concrete Floors, by Wm. McGinnis.

Eng. News Record 3/6/19, page 477. Suggestions made for wetting slag before mixing concrete, so that there will be no tendency for it to "float" to the surface.

- 1919 Specifications for Slag Aggregate, by Amer. Railway Engineering Ass'n.

Railway Age, 3/21/19, page 798. In an attempt to develop a specification for their own use, the A. R. E. A. made a symposium of several existing specifications with no other result than the discovery of a marked lack of uniformity in them.

- 1919 Absorption Tests of Slag, Stone and Gravel Concrete, by O. R. Smith.
Concrete Magazine, 4/19, page 144. Tests on the absorption of several concretes, at varying ages, lengths of immersion and conditions of curing.
- 1919 Use of Slag Cement in Britian.
Extract from British Commerce Reports, 4/10/19, page 227—account of the manufacture of a slag cement by an English Iron Works.
- 1919 Reference to Ore Bank Road in Virginia, by J. H. Fuhrmbacher.
Correspondence re an old macadam road built in Virginia during the Civil War, with slag as the aggregate. One of the oldest slag roads, it has had practically no maintenance.
- 1919 Slag Aggregate in Concrete and Mortar, by Emmanuel Mavaut.
Iron and Steel of Canada, 10/19, page 232. Tests of open-hearth slag in concrete.
- 1919 Crushed Slag as Concrete Aggregate, by Bureau of Standards.
Published by U. S. Bureau of Standards, 11/19. Tests conducted by Bureau of Standards on compressive strength of slag concrete. Specification requirements were tentatively recommended.
- 1919 Technologic Paper No. 130 of Bureau of Standards, by Walter A. Hull.
Published by U. S. Bureau of Standards, 11/12/19. Fire tests on concrete cylinders, in some of which slag was the aggregate. (May be obtained from the Superintendent of Documents, Washington, D. C.).
- 1919 Specifications for Supply of Tarmacadam.
Published by Lancashire County Council, England. Specifications for a tarmacadam construction, using slag.
- 1919 Series of Standard Sizes for Aggregates, by Frank H. Jackson.
Correspondence re proposed sizes for aggregates, to be incorporated in specifications. Crushed slag, slag screenings and slag sand sizes were considered in such a way that the demands could be met commercially.
- 1919 British Slag in Concrete.
Iron Age Magazine, 12/18/19, page 1951. The statements of several English users of Slag, in re its use in concrete foundations, concrete seawalls, concrete floors and miscellaneous concrete products. Experience of 30 to 40 years backs up their statements.
- 1920 Effect of Hydrated Lime and Other Admixtures on Concrete, by Prof. Duff A. Abrams.
A. S. T. M. Vol. 20, Part 2, page 149. Bulletin 8 of Structural Materials Research Laboratory of the Portland Cement Association. The effect of powdered admixtures on the resultant concrete, with reference to compressive strength, tensile strength and absorption. Slag was one of

the admixtures used, and it increased the strength of the concrete. (May be obtained from Portland Cement Association, Chicago, Ill.)

- 1920 Specifications for Sizes of Slag in Highway Construction, by Committee D-4 of the A. S. T. M.

A. S. T. M., Vol. 20, Part I, page 693. Specifications for crushed slag and slag screenings, with regard to sizes only.

- 1920 Specifications for Slag Waterbound Macadam, by Committee D-4 of A. S. T. M.

A. S. T. M., Vol. 20, Part 1, page 698. Slag screenings and crushed slag are included in this specification.

- 1920 Specifications for Shovel-Run and Crusher-Run Slag, by Comm. D-4 of A. S. T. M.

A. S. T. M. Proceed., Vol. 20, Part 1, page 700.

- 1920 Concrete Houses—How They Were Built, by Harvey Whipple.

Concrete-Cement Age Publishing Co., Detroit. A bound book containing a symposium of articles which had already appeared in "Concrete" Magazine, dealing with construction of concrete houses. (May be obtained from the publishers.)

- 1920 Textbook on the Materials of Engineering, by Herbert F. Moore and Harrison Gonnerman.

Published by McGraw-Hill Publishing Co., New York City. Slag is listed as an aggregate in concrete, as a raw material in the manufacture of Portland cement, and as a fire-resistant.

- 1920 Experiments with Blast Furnace Cement, by Prof. H. Burchartz, Berlin, Germany.

Published by Prussian Department of Public Works. Tests with different cements—Slag and non-slag—to determine compressive and tensile strengths, yield and abrasion.

- 1920 Public Roads, by U. S. Bureau of Roads.

A bond volume of the monthly magazine "Public Roads" from 1920 to 1922, which contains several articles on the use of slag in rolled base under brick pavement, and one article on smelter slag in bituminous construction. (May be obtained from the Superintendent of Documents, Washington, D. C.)

- 1920 Tender for Tarmacadam, by Aldershot (England) Urban District council.

English specifications for slag in tarmacadam.

1920. Blast Furnace Slag, by National Slag Association.

National Slag Association, 1/20. Thesis on blast furnace slag, considering its uses in macadam, and in concrete, with details on its chemical composition, weight and color.

- 1920 Use of Slag Aggregate on Elkhart Road, by C. Gray and F. Kellam.

An account of the use of Slag in an Indiana concrete road between Elkhart and Osceola. Compressive strengths ran to nearly 5,000 pounds. Concrete Highway Magazine, 2/20.

- 1920 Blast Furnace Slag, by National Slag Association.

National Slag Association, 2/25/20. Thesis on Slag and its uses, with references to shape, texture, cleanliness, stability, etc.

- 1920 Different Kind of Profiteering, by National Slag Association.

National Slag Association, 3/20. An account of an old macadam road in Wood County, Ohio, in which Slag has been used with remarkable results. A map accompanies it, showing the production areas for Slag in the United States. Photos of roads and buildings, in which Slag was used, occur throughout the booklet.

- 1920 Specifications of National Paving Brick Manufacturers' Association.

Nat. Pav. Brick Man. Ass'n, 7/20. Collection of the specifications of the Association. Slag is included wherever the construction calls for a mineral aggregate, in the form of crushed Slag, granulated Slag, or Slag screenings. (May be obtained from National Paving Brick Manufacturers' Association, Engineers' Building, Cleveland, Ohio.)

- 1920 Concrete Tests of Slag, by U. S. Bureau of Standards.

Bureau of Standards, 7/30/20. Compression test figures on Slag concrete for Wight Bros. Co., Richmond, Va., in comparison with gravel.

- 1920 British Roads for Heavy Traffic, by E. J. Mehren.

Eng. News Rec., 8/5/20, page 273. Tarmacadam construction is the favorite in Britain for heavy-traffic roads, with Slag, preferably, as the aggregate.

- 1920 One of the South's Show Roads, by National Slag Association.

National Slag Association, 9/20. Booklet containing two articles on the use of slag in roads. One deals with Bitoslag construction in Alabama, the other with slag concrete pavement in China.

- 1920 Specifications for coarse-graded Asphaltic Concrete, by Asphalt Association.

Asphalt Association, 9/1/20. Slag is included in this specification.

- 1920 Tenders for Slag Macadam, by City of Manchester, England.
Manchester (England) City Council, 9/11/20. Specifications for the supply of slag in tarmacadam.

- 1920 Report of Street Repairs and Maintenance, by Municipal Research Bureau of Cleveland, O.

Municipal Research Bureau, 10/20. The report advises

the use of slag and granulated slag as bedding course under brick and block. (May be obtained from Municipal Research Bureau, Cleveland, O.)

- 1920 Slag Aggregate Makes Satisfactory Concrete.

Eng. News Record, 10/7/20, page 689, Report of tests at the Bureau of Standards, on several concretes, Slag being one. Compressive strengths were obtained which resulted in tentative specification requirements.

- 1920 Use of Slag in Concrete Pavements, by H. K. Bishop.

University of Michigan Bulletin, 10/16/20. Data on slag concrete used in Elkhart-Osceola road, in Indiana. Compressive strengths and resistance to abrasion are given. Satisfactory concrete roads using slag are noted in Ohio and West Virginia also.

- 1920 Correspondence re "British Builder," by A. C. H. Price.

Correspondence, 12/2/20, re English use of slag concrete, tarred slag, and slag for ballast and for filter-bed media.

- 1920 Railways Using Slag for Ballast, by National Slag Association.

National Slag Association, 12/10/20. A summary of the railroads using slag for track ballast at that date.

- 1920 Demolishing of Ulmer Building, by A. Dray.

Correspondence, 12/22/20, re the demolishing of the Ulmer Building, Cleveland, O., in which the author notes the good condition of the reinforcement when removed from the slag concrete, and the remarkable toughness of the slag concrete itself.

- 1921 Specifications for Production of Slag, by Association of German Iron Works.

This German report covers the manner in which slag should be handled at the furnace, and during preparation for market.

- 1921 Basic Specifications for Tile Work, by Associated Tile Manufacturers.

Summary of the Association's specifications for tile work; slag is included as an aggregate in the concrete bedding-course for tile. (May be obtained from Associated Tile Manufacturers, Beaver Falls, Pa.)

- 1921 Study of the Composition of Slag for Aggregate, by L. G. Carmack.

A. S. T. M. Proceed., Vol. 21, page 976. Engineering and Construction, 7/27/21, page 82. Tests to establish the extent of stability in commercial blast furnace slags. Magnesia was found to narrow considerably the field of instability, and it was noted that slags which did disintegrate, did so within a week of pouring.

- 1921 Wear Tests of Concrete, by Prof. Duff. A. Abrams.

A. S. T. M. Proceed., Vol. 21, Part 2, page 1013. Bulletin 10 of Structural Materials Research Laboratory of

the Portland Cement Association. Tests for compressive strength, resistance to Talbot-Jones abrasion and absorption were made. (May be obtained from Port. Cem. Ass'n, Chicago, Ill.)

- 1921 Bitoslag, the Pavement that Wears Like Iron, by Bitoslag Paving Co., New York City.

Trade Pamphlet on Bitoslag paving construction, with photographs of roads made under that patent—a bituminous concrete using slag for coarse aggregate. (May be obtained from Bitoslag Paving Co., New York City.)

- 1921 Blast Furnace Slag; Data on its Preparation, by Carnegie Steel Co.

Method of processing several varieties of slag—pancake, honeycomb and fork slag, in addition to the more common varieties, air-cooled and granulated. Open-hearth and Bessemer slags are given attention as fertilizers. Figures are given on blast-furnace slag—compressive strength, tensile strength and elasticity in concrete, absorption, expansion, shape, size, etc. (Out of print.)

- 1921 Old Joint Committee Reports, compiled by the National Slag Association.

Summary of reports brought in by the Joint Committee on Concrete and Reinforced Concrete, and of criticism by Comm. C-9 (of the A. S. T. M.) of these reports.

- 1921 Pittsburg General Engineering Regulations, by Pittsburg City Building Code Committee.

City specifications for concrete masonry and concrete building block, in which slag is included. (May be obtained from City of Pittsburg, Pa.)

- 1921 Results of Tests of Different Aggregates, by Pittsburg Testing Laboratory.

Compressive strength figures on Slag, stone and gravel concrete, tabulated along with weight and voids.

- 1921 Ulmer Building, In Reference to, by Jas. R. Gloyd.

Correspondence, 1/4/21, re the demolishing of the Ulmer Building, and the remarkable toughness of the slag concrete in the structure.

- 1921 Steel from Slag Concrete Shows Little Corrosion.

Eng. News Record, 2/3/21, page 212. The steel from the slag concrete in the Ulmer Building, Cleveland, O., showed little corrosion after 15 years.

- 1921 In Wrecked Concrete, Little Corrosion of Reinforcing Shows, by D. P. Jennings.

Concrete, 3/21, page 128. An article on the demolishing of the Ulmer Building, calling attention to the lack of corrosion in the reinforcing when taken from the slag concrete after 15 years. The wrecking of the Plain Dealer building after 13 years is also cited to prove the non-corrosive effect of slag on steel. Both these buildings were in Cleveland.

- 1921 Limitations of Sulphur in Slag for Concrete, by National Slag Association.
National Slag Association, 3/23/21. Symposium of data on the condition of steel after being embedded in slag concrete for from 2 to 19 years, the opinions of several authorities being included, all of which are satisfactory.
- 1921 Long Arch Bridge of Slag Concrete, by W. C. Fry, Jr.
Eng. News Record, 5/19/21, page 840. An account of the Reading arch bridge, in Pennsylvania, constructed of slag concrete, with consequent economy in design and construction.
- 1921 Notes on English Bituminous Road Practice, by A. Dryland.
Eng. News Record, 5/26/21, page 894. An article on the general use of slag for tarmacadam construction in England, preferred because of its superior bonding qualities.
- 1921 Quantities for One Cubic Yard of Concrete, by Fred Hubbard.
National Slag Association, 6/21. Tabulated quantities of materials necessary for one cubic yard of concrete, with slag as aggregate, and assuming a weight of 73 lbs. per cu. ft. and 42% voids.
- 1921 Slag Bases for Brick Roads, by National Slag Association.
Nat. Slag Ass'n, 6/21. Two articles, one on slag bases for brick pavement, and the other on the Fisher Body Co. plant at Cleveland, in which 50,000 cu. yds. of slag concrete were used, the largest building permit ever issued in Ohio up to that time.
- 1921 Proportioning Slag Concrete, by W. L. Leach.
Concrete, 6/21/21, page 131. Method of determining number of parts of slag for a given sand content, by adding 10 to percentage of voids in slag, thus insuring that the voids are filled, and dense concrete results.
- 1921 Wear Tests Show Qualities of Paving Materials.
Eng. News Record, 6/30/21, page 1121. Tests of concrete slabs in a runway at the Bureau of Roads Experimental Farm, Arlington, Va., by means of steel-tired wheels, to determine resistance to impact and rupture and to wear.
- 1921 Resurfacing Old Brick Pavements, by John S. Crandell.
Highway Engineer and Contractor, 7/21. Account of the resurfacing of a brick pavement with tarvia, using slag as aggregate on East Exchange St., Akron, O.
- 1921 German Concrete Houses Poured in One Operation.
Eng. News Record, 8/4/21, page 201. Article on the construction of German concrete houses with slag concrete in which all the forms were set up first, and a lean concrete poured into them. The whole job was completed in 12 days. The concrete could be nailed into, and was a good insulator against heat.

- 1921 Sand Lime Brick Manufacture in England.

Cement Mill and Quarry, 8/5/21. Slag used as one of the aggregates in sand-lime, or in this case slag-lime bricks, in England. They are immune to frost and acid fumes, and are the full equal to clay bricks for durability, in construction of houses, buildings, etc.

- 1921 Cement Production (Electric) from slag.

Rock Products, 8/13/21. Swedish production of cement in an electric furnace, by fusing liquid slag and lime. The resulting product, when air-cooled, falls to a fine powder, which requires little or no grinding.

- 1921 Blast Furnace Slag as a Concrete Aggregate.

Bureau of Standards, 9/21. Tests for compressive strength of slag concrete made at U. S. Bureau of Standards. Experiments with slag as both fine and coarse aggregate were not reassuring, but the lack of workability evident in such a concrete could be overcome by proper proportioning, or by additions of fine sand or hydrated lime. Slag in concrete has no effect on steel reinforcement, and there is no need for a restriction on slag in regard to sulphur content of weight per cu. ft.

- 1921 Concerning Tests of Slag Aggregate, by Prof. Duff. A. Abrams.

Correspondence 10/14/21, in which test figures are given on slag concrete, for compressive strength, Talbot-Jones abrasion, absorption and yield. Comparison is made with other aggregates—pebbles, limestone, granite and trap-rock. The theory is advanced that greater compressive strength follows the grading of the aggregate as it becomes coarser, and at the same time the amount of wear in the Talbot-Jones machine decreases.

- 1921 Paving Economy in Warren, O., by Albert C. Smith.

Roadmaker, Excavator and Grader Magazine, 11/21. The author considers the best type of pavement to be the following: Rolled Slag base, granulated Slag cushion, vitrified brick surface, and asphalt filler. His experience indicates that it is the most serviceable over long periods of time, cost considered.

- 1922 Summary of Specifications in the American Concrete Institute.

Compiled by the National Slag Association, 1922. Specifications include those for concrete sidewalks, concrete floors, building regulations, fireproofing, concrete chimneys, concrete houses, concrete sewers.

- 1922 Atlas Handbook on Concrete Construction, by Atlas Portland Cement Co.

Handbook, published by the authors, giving concrete data for engineers and contractors. Slag is listed as one of the available aggregates for concrete construction. (May be obtained from Atlas Portland Cement Co., New York City.)

- 1922 Flexural Strength of Plain Concrete, by Prof. Duff. A. Abrams.
Amer. Con. Inst. Proceed., Vol. 18, page 20. Bulletin
11 of Structural Materials Research Laboratory of the Port-
land Cement Association. Test figures on slag concrete—
compressive strength, modulus of rupture—in comparison
with concrete from other aggregates—pebbles, limestone and
granite. (May be obtained from Portland Cem. Ass'n.
Chicago.)
- 1922 Photographs of Slag Concrete Structures.
Compiled by the National Slag Association, 1922. Set
of six photographs of slag structures as follows: Concrete
viaduct at Akron, O.; sheet asphalt on slag concrete base in
Philadelphia; slag concrete pavement in Washington county,
Pennsylvania; offices of Carnegie Steel Co. at Youngstown,
O.; Tarbound slag macadam road near Youngstown, Ohio.
- 1922 Summary of Specifications of Bureau of Roads and of Stand-
ards.
Compiled by National Slag Association, 1922. Neither
Bureau has printed formal specifications, but have tentatively
recommended requirements, in both cases for use in concrete
roads.
- 1922 Accurate Proportioning, by Fred Hubbard.
Tabulated quantities for one cubic yard of slag concrete,
assuming 42% voids in the slag.
- 1922 Slag, by New England Slag Co.
Booklet on Slag structures in New England, with
photographs—concrete and macadam roads, concrete bridges,
and concrete buildings. (Out of print.)
- 1922 Sea-going and Other Concrete Ships, by N. K. Fougner.
Published by Henry Frowde and Hodder and Stoughton,
London, England, 1922. Treatise on the subject of con-
crete ships. Slag is given only incidental mention, not being
considered a first-class aggregate by the author.
- 1922 Cements, Limes and Plasters, by E. C. Eckel.
Published by John Wiley and Sons, New York City.
An exhaustive treatment of the subject of cements, limes and
plasters, in which slag occurs as an ingredient in Portland
and in slag cements. The manufacture of cement, concrete
blocks, slag blocks and bricks is followed through the various
countries of South America, North America, and Europe,
and the processes given.
- 1922 Bulletin 21 of National Research Council.
A census of highway research projects then under way
in the United States, in many of which slag was included.
(May be obtained from National Research Council, Wash-
ington, D. C.)
- 1922 Detailed Report of Slag Concrete Highways.
Compiled by National Slag Association, 1922. Sympo-
sium of slag concrete highways in Ohio, Pennsylvania,

Georgia, Indiana, West Virginia, Connecticut, New York and Alabama, with details of construction.

- 1922 Itemized Report of Slag Concrete Highways.

Compiled by National Slag Association, 1/22. Tabulated data from the above report, giving length, width, thickness, etc.

- 1922 Blast Furnace Slag as a Concrete Aggregate.

Compiled by National Slag Association, 1/22. A bibliography of slag literature from 1870 to 1922, in incomplete form.

- 1922 Special Methods Using Slag in Concrete Roads.

Eng. News Record, 1/12/22, page 58. An account of the use of slag concrete in the Cleveland to Akron road, 17 miles long. This is probably the longest slag concrete trunk road in existence.

- 1922 Bureau of Roads on "Outline of Slag Investigation," by U. S. Bureau of Roads.

An outline of the form which an investigation of slag should take, covering absorption, abrasion, compressive strength and expansion of slag concrete.

- 1922 Supplementary Outline for Study of Slags, by U. S. Bureau of Roads.

Supplement to above Outline.

- 1922 Outline for Report Form on Buildings.

Compiled by National Slag Association, 4/29/22. A form for reporting the details of slag concrete buildings—length, width, tonnage, etc.

- 1922 Outline for Report Form on Concrete Highways.

Compiled by National Slag Association, 6/2/22. A form for reporting construction details of slag concrete roads—length, width, thickness, etc.

- 1922 Astonishing But True, by Birmingham Slag Co.

Birmingham Slag Co., 6/28/22. Advertising pamphlet listing 180 miles of slag roads laid in the district covered by this company, in 1922, including the following types: Asphaltic concrete, Penetration macadam, waterbound macadam, sheet asphalt and surface-treated roads. (May be obtained from Birmingham Slag Co., Birmingham, Ala.)

- 1922 Reports of Tests on Slag from Sewage Beds, by J. Chas. Joublanc.

Correspondence, 7/4/22, reporting the results of tests on slag from the Canton, O., sewage disposal beds. The conclusion was reached that the amount of deterioration was almost negligible.

- 1922 Lightweight Concrete.

Canadian Engineer, 8/15/22, page 259. An article advising the use of slag concrete in suspension bridges, arch bridges, towers, etc., where the light weight of slag concrete

may be taken advantage of. The advantage to be secured by this use is set at 30%. Several instances of French bridge and pier construction with slag concrete are cited.

- 1922 Tests of Brick Made from Slag, by E. P. Gangewere.

Concrete, 6/15/22, page 65. Slag concrete brick, with granulated as aggregate, were tested for compression, absorption, shear and modulus of rupture. The conclusion was advanced that they are superior in strength to clay or shale bricks.

- 1922 Slag Concrete Roads, Their Construction and Wear, by C. S. Hill.

Eng. News Record, 9/14/22, page 439. Conclusions based on an inspection of over 100 miles of slag concrete roads, in service from one to nine years. Slag is the equal of the natural aggregates, the only drawback being the pitting of slag concrete surfaces, which was stated to be a defacement rather than a structural damage.

- 1922 Adhesion of Steel and Concrete, and Preservation of Steel in Concrete, by F. C. Lea and R. E. Stradling.

Concrete and Structural Engineering, 10/22, page 635. Notice is drawn to the fact that in slag concrete, the fracture is through the aggregate rather than around it as in other aggregates, which accounts for its greater bond strength with steel. No deleterious effect was noted on steel embedded in slag concrete, the steel being as bright on withdrawal as when placed in position.

- 1922 Duriron Company Correspondence.

Letter, 10/13/22, from the Duriron Co., Dayton, O., in which they state that the word "slag" was used in only a general sense in a former article which had appeared in one of their publications. This article made a slighting reference to the use of slag concrete, but the meaning of the context was not as indicated by the use of the word "Slag."

- 1922 Portland Cement Concrete Roads, by Jas. T. Voshell and R. E. Toms.

Bulletin 1077 of the Department of Agriculture, 10/21/22. Instructions for concrete road construction, including cost, equipment, etc., in addition to the method of laying the pavement proper. Slag may be used as a satisfactory aggregate. (May be obtained from Superintendent of Documents, Washington, D. C.)

- 1922 Boats, Statements on Slag in Concrete.

Correspondence, 7/6/22 to 9/9/22, re a statement by a party connected with the U. S. Shipping Board that slag contained chemicals which were detrimental to reinforcing steel. No data supported this statement, and the author of it was unable to back up his assertion with facts.

- 1922 Slag as Plant Food, or Acid Soil Corrective, by National Slag Association,

National Slag Association, 11/21/22. The conclusion is advanced that the use of slag, either granulated or air cooled, as a soil corrective, is attended with very noticeable benefits, due not to a chemical action between the slag and the soil, but rather a purely physical change in the texture of the soil, allowing greater absorption and drainage.

- 1922 Slag Industry, by H. N. Snyder.

Rock Products, 12/30/22. A review of the slag industry for 1922, with especial reference to the development of screening and crushing operations. Production estimated for 1922 at 6,000,000 tons of slag.

- 1923 Pit and Quarry Handbook, by Complete Service Publishing Co., Chicago.

Book, published by authors, summarizing the pit and quarry industry, covering lime, cement, rock, gravel, etc., and including slag as one of the raw materials in the manufacture of Portland cement. (May be obtained from the publishers.)

- 1923 Specifications for Concrete and Aggregates, by Committee C-9 of A. S. T. M.

Proceed., A. S. T. M. Vol. 23, Part 1, page 220. Notice is given in this report of changes in the specification for coarse aggregate, in order to allow the inclusion of blast furnace slag as a concrete aggregate. (This article also appears in Eng. News Record, 7/5/23, page 22.)

- 1923 Blast Furnace Slag as a Concrete Aggregate, by Raymond Harsch.

Proceed., A. S. T. M., Vol. 23 Part 2, page 255. Conclusions from tests on slag and on slag concrete for Deval abrasion, Talbot-Jones abrasion, compression, absorption, tensile strength; different methods of disposal of slag from the furnace are considered, and crushing and screening operations are outlined.

- 1923 Stenographic Report of the Discussion of Harsch Paper Before A. S. T. M.

Proceed., A. S. T. M., Vol. 23, Part 2, page 274. Discussion principally on the absorption factor in slag concrete, the contention being made on one side that slag absorbed more water than other aggregates, while on the other side the opposite opinion was held, i. e., that it absorbed no more water than other aggregates.

- 1923 Specifications for Road and Paving Materials, by Comm. D-4 of A. S. T. M.

Proceed., A. S. T. M., Vol. 23, Part 1, page 394. Specifications for use of slag in bituminous macadam surface course, in bituminous fine-graded concrete and bituminous coarse-graded concrete. The committee also recommended that

tentative specifications be advanced to standard on the following: Slag for waterbound macadam base and surface courses; and on shovel-run and crusher-run slag for water-bound macadam base course.

- 1923 Specifications for Concrete Aggregates, by Committee C-9 of A. S. T. M.
 Proceed., A. S. T. M., Vol. 23, Part 1, page 626. Specifications for slag to be used as concrete aggregate.
- 1923 Proposed Specifications for Slag Bituminous Macadam Wearing Course, by Committee D-4 of the A. S. T. M.
 Proceed., A. S. T. M., Vol. 23, Part 1, page 712.
- 1923 Specifications for Slag Coarse-graded Bituminous Concrete by Committee D-4 of A. S. T. M.
 Proceed., A. S. T. M. Vol., 23, Part 1, page 714.
- 1923 Proposed Specifications for Slag Fine-graded Bituminous Concrete, by Committee D-4 of A. S. T. M.
 Proceed., A. S. T. M., Vol. 23, Part 1, page 716.
- 1923 Sulphur Limitations, by Committee C-9 of A. S. T. M.
 Proceed., A. S. T. M., Vol. 23, Part 1, page 220. No restriction on the sulphur content in slag was included in Committee C-9's specification, as inspection showed no corrosion of reinforcement in slag concrete.
- 1923 Asphalt Pavements, by Asphalt Association. Asphalt Association, 1923.
 A summary of brochures, circulars and specifications of the Asphalt Association, covering all types of asphalt pavements. Specifications for the different types almost invariably name slag as one of the satisfactory aggregates. An account is also included of a rattler for testing blocks of bituminous mixture. (May be obtained from Asphalt Association, 441 Lexington Ave., New York City.)
- 1923 Sewage Disposal in Mining Towns, by Clinton A. Decker.
 Proceed., Amer. Soc. for Municipal Improvements, 1923, page 86.
 An account of the use of slag in sprinkling filters and sludge beds, in Alabama mining towns.
- 1923 Membership of National Slag Association, Compiled by National Slag Association, 1923.
- 1923 Prominent Jobs Where Slag was Used Exclusively. Compiled by National Slag Association, 1923.
 A summary of large construction jobs in which slag concrete was used exclusively.
- 1923 Slag Concrete Buildings in Ohio. Compiled by National Slag Association, 1923.
 Symposium of slag concrete buildings in Ohio, including factories, churches, hotels, etc., giving amount of slag used, and other details of construction.

- 1923 Slag Concrete Buildings in United States. Compiled by National Slag Association, 1923.
Symposium of Slag concrete buildings in Georgia, Alabama, Florida, South Carolina, Pennsylvania, Connecticut, New York and Massachusetts, giving amount of slag used, and other details of construction.
- 1923 Summary of City Building Codes. Compiled by National Slag Association, 1923.
Summary of the City Building Codes of Cleveland and Youngstown and Warren, O.; Pittsburgh and Philadelphia, Pa.; and Buffalo, N. Y., in all of which slag is included.
- 1923 Summary of Specifications in American Concrete Institute. Compiled by National Slag Association, 1923. American Concrete Institute specifications for concrete sidewalks, floors, sewers, chimneys and houses; for building regulations and for fireproofing; and the progress report on concrete roads and pavements, slag is included in all of these.
- 1923 Summary of State Highway Specifications. Compiled by National Slag Association, 1923.
Specifications for the use of concrete in highway structures in the following states include slag: Alabama, Florida, Georgia, Indiana, Kentucky, Maryland, Mississippi, New Jersey, New York, North Carolina, Ohio, Pennsylvania, Tennessee, Utah and West Virginia.
- 1923 Summary of Trade Association Specifications, Compiled by National Slag Association, 1923.
Specifications of the National Paving Brick Manufacturers' Association and of the Associated Tile Manufacturers, both of which include slag.
- 1923 Protection of Steel by Concrete.
Canadian Engineer, 1/16/23, page 157. An article reporting the tests of Lea and Stradling of University of Birmingham (England), in which the conclusion is reached that the steel was not affected in the least by inclusion in slag concrete, but was as bright on withdrawal as when placed.
- 1923 Salvaging and Maintaining Macadam, by Alex. W. Muir.
Eng. News Record, 1/25/23, page 156. The author's experience in New Jersey indicates that equally good results may be obtained by the use of crushed slag for cold surface treatment work, in place of stone.
1923. Completion of Notable Concrete Viaduct.
Scientific American, 2/23, page 99. Account of the completion of the North Hill viaduct at Akron, O., in which 100,000 tons of slag concrete were used. The viaduct is 72 feet wide and 2,180 feet long, and cost a million and a quarter.
- 1923 Fire Resistance of Concrete Building Units, by Committee P-5 of American Concrete Institute.
Concrete Products, 3/23, page 27. Proceed., Amer.

Con. Institute, Vol. 19, page 331. Fire tests of concrete building units conducted at the Underwriters' Laboratory, Chicago, in co-operation with Committee on Fireproofing of the American Concrete Institute. The units containing slag made a very satisfactory showing.

1923 Disposal of Waste Slag.

Earth Mover, 3/23, page 8. Methods of disposal of slag from blast furnaces include (1) manufacture into cement (2) use of air-cooled slag in highways, railway ballast and concrete (3) filling waste ground or pits. Two instances are noted in this article of projects for reclaiming waste land for industrial building sites, by slag fills, one at Niles, O., and one at Pulaski, Pa.

1923 Correspondence with Prof. Giesecke of University of Texas, by National Slag Association.

Correspondence, 3/10/23, in which the point is brought out that the stability of a slag is assured when the magnesia content reaches 10% regardless of other components and the alumina content 15% regardless of other components.

1923 Utilization of Waste Material, by A. W. Allen.

Engineering and Mining Journal, 3/17/23. Suggestion for the use of smelter slag in grinding balls for the reduction of copper ore to sand. Addition to the slag of a foreign substance is advised, in order to obtain the required hardness and toughness.

1923 Results of Physical Tests of Rock, by U. S. Bureau of Roads.

Bulletin 1132 of U. S. Dept. of Agriculture, 3/21/23. The results of tests extending from 1916 to 1921, which included abrasion, absorption, hardness, toughness and weight on the aggregates of the United States and Canada. Both blast furnace and smelter slag were tested. (May be obtained from Superintendent of Documents, Washington, D. C.)

1923 Bond Strength of Slag Concrete.

Canadian Engineer, 3/27/23, page 365. It is noted that slag concrete at nine months possessed equal, and in some cases greater bond strength in comparison with gravel concrete.

1923 Stone Screenings as Fine Aggregate, by Prof. Duff A. Abrams.

Concrete, 4/23, page 128. The conclusion is reached that good concrete can be made with stone or slag screenings, though the mixture lacks something in workability. The strengths attained by the mortars containing slag screenings were about equal to those from natural-sand mortars.

1923 Correspondence re Efficient Operation of Railroads.

Correspondence, 4/23, between Herbert Hoover, Secretary of Commerce, and National Slag Association, regarding full use of railway equipment during the war.

- 1923 Cement from Blast Furnace Slags.
Scientific American, 4/23, page 263. An article reprinted from the Journal of the Society of Chemical Industries, reporting two methods of making cement from slag: (1) By fusing slag and lime in an electric graphite furnace, and grinding the resulting clinker. (2) Addition of alumina to the slag, making it basic and reducing its melting point, so that it can take up more lime; the resulting clinker is ground to cement.
- 1923 Pioneering Beyond the Rim, by Floyd W. Parsons.
Saturday Evening Post, 5/5/23, page 22. Article on research in the United States, and the possibilities of industrial development from that source. In that connection the possibility is noted of slag being tried for farm fertilizer, tested in cements, made into glass, ground into paint, calendered into paper, blown into thermal insulation, turned into asbestos, put into dynamite or injected into medicines.
- 1923 List of Slag Concrete Chimneys.
Compiled by National Slag Association, 6/23. Summary of slag concrete chimneys in Cleveland, Lorain and Youngstown, O., and in Albany, Ga., giving data on construction.
- 1923 Plain Slag Concrete Roads in Atlanta, Ga.
Compiled by National Slag Association, 6/23. List of slag concrete roads in Atlanta, Georgia; one is noted as being finished with rubber hose.
- 1923 Future of Hard Stone Quarries, by William Shaw.
Quarry Managers' Journal, 7/23. Paper suggesting relief for English conditions, under which slag is being used in preference to stone in highway construction. The author, as a quarryman, is in favor of stone, but admits that the slag people succeeded in making good roads.
- 1923 New Specifications Concerning Materials.
Eng. News Record, 7/5/23, page 22. Report of the annual meeting of the A. S. T. M., in which recognition of slag as a concrete aggregate and as a material for highway construction generally, was accorded.
- 1923 Detailed Report of Slag Concrete Bridges.
Compiled by National Slag Association, 8/23. Summary of slag concrete bridges in Alabama, Connecticut, Georgia, Indiana, Maryland, New York, Ohio, Pennsylvania and West Virginia, with details of construction.
- 1923 Tar Splashes, by Wm. Challoner.
Quarry Managers' Journal, 8/23. Discussion of different aggregates for English tarmacadam construction. The author, a quarryman, prefers granite to slag, but admits that slag absorbs the volatile oils of a thin tar and leaves a more viscous binder for coating the surface of the aggregate, which is a decided advantage.

- 1923 Value of Bitumen in Tarmacadam, by J. S. Killick.
Quarry Managers' Journal, 8/23. Paper dealing with the advantages of adding bitumen to the tar used in English tarmacadam construction, giving it body and allowing of quicker set of the road. The author draws attention to the fact that increasing quantities of this type of construction are being laid with slag as the aggregate.
- 1923 Results of Compression Tests, by U. S. Bureau of Roads.
Bureau of Roads, 8/18/23. Figures for tests on compressive strength and modulus of elasticity, with slag as the coarse aggregate in each case, and the fine aggregates varying between Potomac River sand, granulated slag and slag sand. The natural sand gave the better concrete by a small margin than the slag fine aggregate.
- 1923 Tentative Specifications for Concrete Pavements, by U. S. Bureau of Roads.
Bureau of Roads, 8/31/23. Specifications including slag as an aggregate.
- 1923 Discussion of Workability and Yield of Slag Concrete, by National Slag Association.
National Slag Association, 11/23. This paper is in the nature of a Digest of the paper read by Raymond Harsch before the A. S. T. M., 1923, and reaches the conclusion that there is no apparent reason why blast furnace slag should require more sand or cement for good workability than other aggregates.
- 1923 Limitations on Slag in Different States.
Compiled by National Slag Association, 9/23. Symposium of specifications for slag, from 15 states, the American Concrete Institute, the A. S. T. M., Bureau of Roads, etc., covering concrete, bituminous and macadam construction.
- 1923 Superiority of Granite as Concrete Aggregate, by Humphrey P. Morgan.
Quarry Managers' Journal, 9/23. The author, an English engineer, prefers granite to slag as concrete aggregate, principally on account of the sulphur content of slag, but he also mentions pitting, voids and absorption as points on which granite has an advantage.
- 1923 Tar-Macadam, Views on its Manufacture, by S. McPherson.
Quarry Managers' Journal, 9/23. The author prefers stone to slag as an aggregate in English tarmacadam, but admits that the reputation of slag tarmacadam is greater than that of other tarred macadam. This, however, he attributes to publicity.
- 1923 Investigations on Proportioning, by R. Feret.
Revue de L'Ingenieur, 9/23. This is a detailed account of methods of proportioning, with particular attention to the water-cement-ratio theory. Slag is indicated as one of the typical aggregates for use in French concrete.

- 1923 Digest of "Strength of Concrete."
Analyzed by National Slag Association, 10/23. A digest of the book listed in the following paragraph—"Strength of Concrete," by Talbot and Richart.
- 1923 Strength of Concrete, by A. N. Talbot and F. E. Richart.
Bulletin 137 of University of Illinois Experiment Station, 10/15/23. Thesis on the method of proportioning concrete which is based on the voids content of the concrete. (May be obtained from University of Illinois.)
- 1923 Further Digest of "Strength of Concrete."
Analyzed by National Slag Association, 10/23. A further digest of "Strength of Concrete," in which the point is made that the amount of voids in concrete is not relative to the void content of the aggregate, but to the void content of the mortar alone, as all the voids in the coarse aggregate are filled with mortar.
- 1923 Report of the Chief of the Bureau of Roads, by Thos. H. McDonald.
Bureau of Roads, 10/15/23. The report states: "Results indicate that slag is suitable for such use (concrete aggregate) and that the strength of slag concrete is equal to the strength of concrete in which other acceptable aggregates are used." (May be obtained from the Superintendent of Documents, Washington D. C.)
- 1923 Basic Slag as Phosphate Fertilizer, by W. H. Waggaman and H. W. Easterwood.
Chemical and Metallurgical Engineer, 11/12/23, page 873. Account of the use of Basic Bessemer Slag as a source of phosphate for fertilizer. Basic open-hearth slag is not so valuable for that purpose. The availability of basic slag for fertilizer is appreciably affected by the rate of cooling after leaving the furnace.
- 1923 Structure Resists Wreckers' Blasts.
Cleveland "Plain Dealer," 11/23/23. An account of the tearing down of the Higgins-Babcock Building in Cleveland, O.; the superintendent of the wrecking crew stated that in 30 years he had never seen a building so solidly constructed. The difficulty was such that at least one section had to be left intact, being impossible of removal. The building was of slag concrete.
- 1924 Specification for Concrete Pavements, by Committee on Specifications for Concrete Pavements of the A. S. M. I.,
Proceed. Amer. Society for Municipal Improvements, page 376. Specifications include slag as aggregate.
- 1924 Specifications for Slag for Highway Construction.
Compiled from proceedings of A. S. T. M. by National Slag Association, 1924. A summary of all specifications and tentative specifications in the American Society for Testing Materials in which slag is included—for bituminous

coarse-graded concrete; for commercial sizes of broken slag; for bituminous fine-graded concrete; for bituminous concrete base; for bituminous macadam base and wearing course; for waterbound macadam base and wearing course, and for shovel- or crusher-run base.

- 1924 Proposed Recommended Practice for Compression Tests, by American Society for Testing Materials, Committee C-9.
A. S. T. M. Tentative Standards, 1924, page 211.
Proceed. A. S. T. M., 1921, Vol. 21 page 579. Detailed procedure for making compression tests of concrete, and of the aggregates.

- 1924 Influence of Aggregates on Shrinkage of Concrete, by Cloud M. Chapman.

Proceed. A. S. T. M., Vol. 24 part 2 page 767. Tests conducted to determine just what effect the fine aggregate in the top layer of a concrete floor could have on the expansion or contraction of that upper layer. It was found that mortars and concretes containing varying fine aggregates varied in the degree of movement, slag screenings and sand showed as little contraction as any and much less than some fine aggregates.

- 1924 Laboratory Investigations of the Influence of Curing Conditions and Various Admixtures on the Life of Concrete Stored in Sulfate Solutions, by Dalton G. Miller.

Proceed. A. S. T. M. Vol. 24 Part 2 page 847. Compression tests were run on specimens after storing in sulfate solutions. Various curing conditions indicated that curing in steam lengthened the life of the concrete in sulfate solutions; and that additions of ground blast furnace slag up to 40% by weight of concrete thought it added nothing to the compressive strength.

- 1924 Accelerated Wear Tests of Concrete Pavements by F. H. Jackson and J. T. Pauls.

Proceed. A. S. T. M. Vol. 24 Part 2 page 864. The results of the tests conducted at the Arlington Experimental Farm of the U. S. Bureau of Roads, at Arlington Va., including compression modulus of rupture, modulus of elasticity, Deval abrasion, and the circular track test. The latter consisted of sections of concrete laid in a continuous track, over which a heavily-loaded truck ran 300,000 times with solid tires and 50,000 times with skid chains. Four of the sections contained as coarse aggregate commercial blast furnace slag, and one also contained slag sand as fine aggregate.

- 1924 Concrete Products: Their Manufacture and Uses, by Wallace R. Harris.

International Trade Press, Chicago, Ill. Book on the uses and manufacture of all kinds of concrete products, from title to burial vaults. Slag is listed as one of the aggregates.

Note is made also of smelter slag having been used in concrete for ballast blocks in submarines. (May be obtained from publishers.)

- 1924 Editor's Ready Reference Book on Cement and Concrete, by Portland Cement Association.

Portland Cement Association, 1924. Booklet on uses and manufacture of cement and concrete. Slag is listed as one of the raw materials used in the manufacture of Portland cement. (May be obtained from Portland Cement Ass'n, Chicago, Ill.)

- 1924 Standard Specifications for Concrete and Concrete Aggregates, by Amer. Society for Testing Materials.

Portland Cement Association, 1924. Summary of specifications in A. S. T. M., covering the use of slag as a concrete aggregate, as well as tests for consistency, weight, compression tests, etc. (May be obtained from Portland Cem. Ass'n, Chicago, Ill.)

- 1924 Instructions for the Manufacture of Slag, by Association of German Steel Mfrs.

Stahl und Eisen, 1924, page 590. Specifications for manufacture and handling of slag, for use in concrete, only acid slag being allowed. Quick cooling of the slag is advised.

- 1924 Blast Furnace Slag, by National Slag Association.

National Slag Association, 1/24. Explanation of the nomenclature of slag, the size into which it is divided commercially, and the uses to which the various sizes are put.

- 1924 Granulating Pit Data, by National Slag Ass'n.

National Slag Association, 1/24. Suggested form to be filled in and used for gathering data on dimensions, etc., of granulating pits.

- 1924 Words of Wisdom.

Quarry Managers' Journal, 1/24, page 193. One of the contributors expresses the opinion that slag is very unsuitable for concrete aggregate, due to its sulphur content attacking steel in reinforced concrete, and due to its porosity.

- 1924 Present Use of Slag Concrete Aggregate.

Rock Products, 1/12/24, page 38. The 50 slag-crushing plants in the U. S. in addition to devoting 70% of their tonnage to concrete, distribute 25% of it to ballast, 1% to roofing and 4% to miscellaneous, as slag brick, concrete block, etc. Slag tonnage for 1923 given as about 7,000,000. The article also includes a summary of the paper read by Raymond Harsch before A. S. T. M. in 1923.

- 1924 A. B. C. of Good Paving.

National Paving Brick Manufacturer's Ass'n, 1/16/24. Booklet on the advantages of brick pavements, with rolled slag or slag concrete bases, and a bedding course of slag sand or granulated slag.

- 1924 Slag for Concrete Road Mix is O. K.'d, by C. D. Buck.
Philadelphia "North American," 1/28/24. Delaware State Highway Department laid experimental sections of concrete roads, including slag. Crack surveys showed a record in minimum of cracking in the slag concrete road. Economy was also a feature in the slag concrete construction, a saving of \$1,155.00 per mile being effected.
- 1924 Reinforced Concrete Structure Resists Wreckers' Blasts.
Concrete, 2/24, page 73. An account of the difficulty encountered in wrecking the Higgins Building, Cleveland. Both slag and gravel concrete were used, and the steel from from all concrete was taken out clean and blue, showing no effect from the sulphur content of slag, after being embedded for 16 years.
- 1924 Steel Still Bright in Old Slag Concrete, by Wilbur J. Watson.
Eng. News Records, 2/24, page 358. Further account of the difficulty of wrecking the Higgins Building, Cleveland, which was almost entirely slag concrete. The few gravel columns protected the steel reinforcement equally as well as the slag concrete, but were not so tough, and were more easily drilled for blasting.
- 1924 Reconsolidated Slag, by Prof. Duff A. Abrams.
Correspondence, reporting tests on reconsolidated slag sand, taken from street car tracks in Chicago. This slag, after being rolled in, "Set up" into a sort of concrete, due to the cementing qualities of the slag. The tests showed no deviation from the usual chemical analysis of slag.
- 1924 Rapid-hardening Slag Cement.
Rock products, 2/23/24, page 40. A rapid-hardening, slow-setting French slag cement, of normal chemical composition, which attains the strength of Portland cement in 7 days.
- 1924 Sizing Slag, by Frank H. Jackson.
Paper read before meeting of National Slag Association, 3/28/24, on the duplication of sizes in engineers' individual specifications, suggestions are made on the advisability of standardizing as much as possible those sizes capable of being produced commercially.
- 1924 Use of Slag in Bituminous Roads, by B. A. Anderton.
Paper read before meeting of Nat. Slag Ass'n, 3/28/24, on the use of slag in bituminous construction, and the possibilities of expansion of its uses along that line.
- 1924 Uses of Slag, by P. H. Bates.
Paper read before the meeting of National Slag Association, 3/28/24, on the particular use of slag in Eisen and Hoehoven cements. The Eisens have almost as great strength as Portlands, and resist weathering much better. These cements are of German manufacture.

- 1924 Workability and Yield, by Jos. C. Pearson.

Paper read before meeting of National Slag Association, 3/28/24, in which the point is made that the oversanded mixture is the logical solution of the problem of workability of slag. The yield of slag concrete is admittedly slightly less than that of gravel, but this is offset by the increased strength due to bond of pitted surfaces.

- 1924 Sewage Treatment in the United States, by H. H. Wagenhals, E. J. Theriault and H. B. Hommon.

Bulletin 132 of U. S. Public Health Service, 4/24. Summary of data from 12 sewage disposal plants, in 3 of which slag was used as filter-bed material, i. e., at Alliance and Canton, O., and at Reading, Pa. (May be obtained from Superintendent of Documents, Washington, D. C.)

- 1924 Cross-section of Blast Furnace.

Photostat, 4/4/24, of drawing of the cross-section of a blast furnace, showing process of reduction, fusion, etc.

- 1924 Crushed Limestone versus Slag Aggregate, by John W. Stull.

Rock Products, 4/5/24, page 58, 68. The opinion of a quarry-owner on the use of slag as concrete aggregate is decidedly unfavorable, but he admits that slag has its place in concrete construction, "as a cheap substitute for limestone."

- 1924 High Points of Joint Committee Report, by Norman W. Stineman.

Stineman points out that the current report of the Joint Committee on Concrete and Reinforced Concrete admits under the heading "other inert materials" not only slag but brickbats, chats, etc.—the indefiniteness of the report defeating its purpose.

- 1924 Tentative Standard Methods of Testing, by U. S. Department of Agriculture.

Bulletin 1216 of Department of Agriculture, 5/24. Adopted by the Amer. Ass'n of State Highway Officials, and approved by the Department of Agriculture—these tentative standard methods of sampling and testing road materials include both slag and slag screenings. (May be obtained from Superintendent of Documents, Washington, D. C.)

- 1924 Wear of Concrete Pavements Tested, by F. H. Jackson and J. T. Pauls.

Public Roads, 5/24, page 1. Article copied from "Accelerated Wear Tests of Concrete Pavements."

- 1924 Layout of Test Sections at Arlington, by U. S. Bureau of Roads.

Public Roads, 5-24, page 4. An outline of the layout sections for the tests in the above article—"Wear of Concrete Pavements"—giving the different conditions under which the sections were laid, the different materials, mixes, etc.

- 1924 Report on Hollow Concrete Building Units, by Underwriters' Laboratories.
Underwriters' Laboratories, 5/24. Tests on concrete building units for resistance to fire. This also appeared in the Proceedings of the American Concrete Institute under "Fire Resistance of Concrete Building Units." (May be obtained from Underwriters' Laboratory, Chicago, Ill.)
- 1924 To Problems Committee of National Slag Association.
Thesis, read at the meeting of the National Slag Association, 5/16/24, on the possibilities of developing new uses for slag and enlarging the old ones.
- 1924 Digest of "Rural Highways and Pavements."
Analyzed by National Slag Association, 5/28/24. Book by Wilson G. Harger, dealing with types of pavement suitable for rural districts. Slag is advised for use in all types. (May be obtained from McGraw-Hill Publishing Co., New York City).
- 1924 Digest of "Construction of Roads and Pavements."
Analyzed, 7/11/24, by National Slag Association from book by Thos. R. Agg. The author believes that in time a "satisfactory coarse aggregate" will be produced from slag. (May be obtained from McGraw-Hill Pub. Co., New York City).
- 1924 Digest of "American Rural Highways." Analyzed, 7/11/24, by National Slag Association from book by Thos. R. Agg. (1920). The author makes only passing mention of slag in macadam construction, referring to its good cementing properties. (May be obtained from McGraw-Hill Pub. Co., New York City.)
- 1924 Modern Slag Plant Built in Record Time.
Rock Products, 7/26/24, page 19. Account of the erection of slag plant at Reading, Pa., and of the processing through which the slag passes in order to become a finished product.
- 1924 Henry Ford's Cement Plant in Operation, by Geo. M. Earnshaw.
Rock Products, 8/9/24, page 25. An account of the manufacture of Portland cement by the wet process, with slag and limestone as the raw materials, at the River Rouge plant of the Ford Motor Co. It is a true Portland, made from granulated slag from Ford's own furnaces.
- 1924 Asphalt Pocket Reference for Engineers, by Asphalt Association.
Asphalt Association, 8/19/24. Booklet with reference tables, condensed specifications, etc., for the different types of asphaltic highway construction. Slag is included in each type as a suitable aggregate. (May be obtained from Asphalt Association, New York City.)

1924 Acoustics and Plaster.

Scientific American, 9/24, page 165. Tests on a sound-absorbing plaster, whose aggregate was Bessemer Slag. The experiments were successful, producing a plaster that absorbed 10 times as much sound as ordinary plaster.

1924 Accelerated Wear Tests of Concrete Pavements.

Rock Products, 9/6/24, page 52. A resume of the results of the Arlington Track tests, which appeared in detailed form in Public Roads Magazine and in A. S. T. M. Proceedings.

1924 Report of Crushing Tests, by Allegheny County Department of Public Works.

Reports, 10/2/24, from Bureau of Tests of the County on tests conducted with Lumnite cement and slag, in concrete. Compressive strengths indicated 28-day concrete in 24 hours.

1924 Manufacture of Slag Concrete Brick, by C. E. Ireland.

Proceed., Amer. Iron and Steel Institute, 10/24/24. An account of the processing of concrete brick made by the Birmingham Slag Co., with slag as aggregate. The brick is waterproof, free from deformities, and bonds well with the mortar.

1924 Ohio and Pennsylvania Test Roads Emphasize the Subgrade.

Eng. News Record, 10/30/24, page 699. Outline of layout and construction of test roads, using different materials for subgrade under concrete pavements—Granulated slag, sand, gravel and cement-clay.

1924 Constitution of Blast Furnace Slags, by R. S. McCaffery.

Iron Age, 10/30/24. Petrographic study of slags—the conclusion is reached that the four constituents of slag—silica, lime, alumina and magnesia—combine to form 17 compounds in slag.

1924 New Titan Cement Patented by Eckel.

Concrete, 11/24, page 91. A process for making cement and iron simultaneously. Lime is fused with titaniferous ore, and the resulting slag ground to cement fineness, which is the Titan cement of the patent. The cement attains very high early strength, and at all ages is superior to Portland.

1924 Make Slag Screenings into Concrete Brick, by C. E. Ireland.

Rock Products, 11/15/24, page 62. Article copied from a paper which is listed on previous page of this Bibliography under "Manufacture of Slag Concrete Brick."

1924 Design and Control of Concrete Mixtures, by Portland Cement Association.

Portland Cem. Ass'n, 12/24. Booklet on the design of concrete by means of the water-cement-ratio-theory of proportioning. Practical examples are worked out, and a very clear explanation is given of the steps necessary in

designing a mix for a given strength. (May be obtained from Port. Cem. Ass'n, Chicago, Ill.)

- 1924 Concrete Data for Engineers and Architects, by Portland Cement Association.

Port. Cem. Ass'n, 12/12/24. Concrete data covering: Excess of mixing water, watertight concrete, grading of aggregates; colorimetric tests, rich mixtures. Thorough mixing; and proper curing. (May be obtained from Portland Cement Association, Chicago, Ill.)

- 1924 City of Detroit Builds Heavy Traffic Pavements.

Eng. News Rec., 12/18/24, page 987. An account of the policy of the City of Detroit, building concrete pavements for heavy traffic, with slag as one of the available aggregates, but penalized by volume $1:2\frac{1}{2}:4$ to $1:2\frac{1}{2}:4\frac{1}{2}$.

- 1925 Proportioning Concrete Materials for Highway Construction, by Geo. W. Hutchison.

Amer. Con. Inst. Proceed., Vol. 21, page 148. The conclusion is advanced that decrease in size of aggregate increases compressive strength of concrete and also its resistance to impact. Oversanded mixtures give equal strengths with normal mixtures.

- 1925 Recommended Building Code, by Portland Cement Association.

The Building Code, compiled and published by the Portland Cement Association, advises the use of blast furnace slag as one of the aggregates in concrete masonry construction, and also in concrete block and tile. (May be obtained from Portland Cement Ass'n, Chicago, Ill.)

- 1925 Report of Committee E-5 of American Concrete Institute.

Amer. Con. Institute, Proceed., Vol. 21, page 524.

The Report of Comm. E-5 on Aggregates defines blast furnace slag and advised its incorporation in specifications as concrete aggregates.

- 1925 Full-strength 28-day Concrete in 24 hours, by Atlas Cement Co.

Pamphlet by the Atlas Cement Company, advertising the rapid-hardening aluminated cement, Lumnite, produced by that company. One instance is cited of a quick repair job on a culvert and roadway, with Lumnite cement and slag aggregate, in Allegheny County, Pa. (May be obtained from Atlas Cement Co., New York City.)

- 1925 Architects' and Engineers' Built-up Roofing Reference Series, by Barrett Company.

Specifications, 1925, of the Barrett Co., for slag for stoop and flat roofs. (May be obtained from Barrett Company, New York City.)

- 1925 Pit and Quarry Handbook, by Complete Service Publishing Co., Chicago.

Handbook of the industry for 1925. Slag is listed as one of the constituent materials in Portland cement, Eisen Portland cement and slag cement, the latter two manufactured in Germany. Test figures by Bureau of Roads are given on slag for absorption, Deval abrasion, hardness, toughness and cementation. Smelter slag received similar treatment.

- 1925 Recommended Requirements for Masonry Walls; U. S. Dept. of Commerce, 1925.

Suggested specification requirements for construction of masonry walls, including slag as one of the available aggregates. (May be obtained from Superintendent of Documents, Washington, D. C.)

- 1925 I. C. S. Concrete Engineers' Handbook; by International Correspondence Schools, Scranton, Pa.

Handbook on concrete construction, specifying slag as one of the aggregates, and noting the use of slag in slag cement. (May be obtained from authors.)

- 1925 Sampling and Testing of Highway Materials; by Wm. H. Barton and Louis H. Doane.

McGraw-Hill Publishing Co., New York City, 1925. Methods of sampling and testing materials, with specifications for their use in highways, copied from the American Society for Testing Materials. Definitions are given for slag, clinker and aggregate. Slag is included as both fine and coarse aggregate.

- 1925 Proceedings of Fourth Annual Meeting of Highway Research Board.

National Research Council, 1925. H. H. Scofield notes the use of slag concrete in Elkhart-Osceola road, in Indiana, and suggests modification of Talbot-Jones and Deval tests for abrasion so as to make them representative. Wear tests on the road itself are advised. (May be obtained from National Research Council, Washington, D. C.)

- 1925 Slag Concrete Products Plant in England; by Bolekow, Vaughan Co., Middlesborough, England.

Booklet, by the authors, on their slag concrete products, which include paving slabs, curbs, building blocks, copings, building brick, paving stone, etc. Basic open-hearth slag is also sold for fertilizer, and crushed blast furnace slag for ballast and roads.

- 1925 Slag Base Serves Well Under Brick Pavement; Highway Engineer and Contractor, 1/25, page 46.

The experience of Farrell, Pa., with granulated slag base under brick pavement has been very satisfactory. Photo shows again the phenomenon of "setting up" of the granulated slag into a very fair representation of concrete.

- 1925 Excellent Progress on Long Paving Contracts; by Fred E. Swineford.
Report, 1/25, on the completion of 15-mile stretch of slag concrete in Ashtabula County, Ohio, on which exceptionally good time was made. Compressive strengths of samples from batches and from the pavement showed very high values.
- 1925 Peerless Super-Cement Booklet; by Peerless Portland Cement Co., Detroit, Mich.
Booklet, published by Peerless Port. Cem. Co., 1/25, on concrete—mixing, placing and finishing pavements. Slag is specified as aggregate, and a photograph of a slag concrete bridge at Youngstown, O., occupies the cover of the booklet. (May be obtained from the authors.)
- 1925 Combining Sand and Slag; Concrete, 2/25, page 57.
Instructions by the Ferro-Concrete Company to its fieldmen, to use greater quantities of slag for a given mix, i. e., for a 1:2:4 mix use 1:2:4½ with slag. Dry mixes are to be used.
- 1925 Bricks from Blast Furnace Slag.
Civil Engineering, 2/20/25. Account of the process of manufacture of slag-lime brick in England. The crushing strength and porosity of this brick are equal to burnt clay brick.
- 1925 Chilton County Concrete Road Attracting Attention.
Industrial Index, 7/29/25, page 50. Seventeen and a Half Mile Concrete Road tests 4,633 lbs. Manufacturers' Record, 2/26/25. Account of the tests conducted on concrete cylinders, which showed a compressive strength averaging 4,600 lbs. with a maximum of 6,271 lbs.—concrete was designed for 3,000 lbs. (May be obtained from Birmingham Slag Co., Birmingham, Ala.)
- 1925 Cements from Slags in France; by Pierre Prevost, Paris, France.
Concrete, 3/25, page 40. Large amounts of slag sand are used in France in the manufacture of various cements: Artificial Portland, Eisen Portland, and Slag Cements. Tensile and compressive strengths of mortar specimens are given, in this article.
- 1925 Recent Conclusions in Highway Research; by A. T. Goldbeck.
Concrete, 3/25, page 91. Resume of conclusions from the Arlington Circular Track tests.
- 1925 Gazing on Cement Products; by P. H. Bates.
Concrete, 3/25, page 89. Proceed., Amer. Con. Inst., Vol. 21, page 126. In this discussion, a general reference to slag is made, as being one of the typical aggregates.
- 1925 Road and Street Standards Specifications; by Committee S-6 of American Concrete Institute.

Concrete, 3/25, page 106. Proceed. Amer. Con. Inst., Vol. 21, page 537. This Committee, that on Concrete Roads and Pavements, excepted slag from the wear test that was demanded of other aggregates in their specifications.

- 1925 Abstract of Oral Report of Problems Committee; by L. A. Beeghly.

Report 4/21/25, of the Problems Committee of the National Slag Association. Note is made of experiments having been made with slag as both fine and coarse aggregate, with satisfactory results.

- 1925 What We Learned Constructing 17 Plants; by W. E. Bliss.

Paper read before meeting of National Slag Association, 4/21/25, giving the history of screens and crushers once used in the production of crushed slag, and an account of the equipment now used.

- 1925 Manufacture of Slag: Its Use in Bituminous Roads; by H. M. Sharp.

Paper read before meeting of National Slag Association, 4/21/25, on the use of slag in bituminous construction, including the patented types Warrenite and Bitoslag.

- 1925 Processing Fine Slag for Wall Plaster; by H. N. Snyder.

Paper read before meeting of the National Slag Association, 4/21/25, on the processing of granulated slag to produce a sand suitable for wall plaster and for fine aggregate in concrete. Tensile and compressive strengths of mortar from this aggregate run 120% that of mortar with Standard Ottawa sand.

- 1925 Salient Features of Portland Cement Association Short Course; by W. H. Brooks.

Paper read before meeting of National Slag Association, 4/21/25, on the short course in design of concrete given by the P. C. A. The Chilton County Slag concrete road, in Alabama, is quoted to prove the practicability of the Designed Mix as applied to slag. The concrete was designed for 3,000 lbs., but averaged 4,633 lbs.

- 1925 Use of Slag Aggregate in Concrete Pipe; by H. N. Spice.

Paper read before meeting of National Slag Association, 4/21/25, reporting compression and absorption tests on slag concrete pipe. The opinion is given that slag concrete pipe will stand breaking, absorption and percolating tests as well as other aggregates.

- 1925 Standard Slag Company Builds 17 Plants.

Rock Products, 5/30/25, page 1. In noting the construction of this plant, attention is also drawn to the increasing use of slag as concrete aggregate and as a road-building material generally. Experiments are also reported on an all-slag concrete—both fine and coarse aggregate. A very satisfactory concrete, both from the standpoint of workability and strength, was obtained.

- 1925 Editor Visits City Engineer.
Eng. News Record, 6/25, page 977. The editor's visit to Lynchburg, Va., brought out the fact that the slag-penetration type of construction prevailed, even on rather steep slopes, for secondary streets.
- 1925 Contractor's Atlas.
Atlas Portland Cement Company, 6/25. Booklet on concrete construction, with copied specifications from U. S. Bureau of Standards and from A. S. T. M., in both of which slag is included as an aggregate. (May be obtained from Atlas Portland Cement Co., New York City.)
- 1925 City of Cortland Paving Inspection.
City of Cortland, N. Y. 6/4/25. The itinerary of an inspection trip through the City of Cortland, over penetration macadam and asphaltic concrete in which the aggregate was open-hearth slag.
- 1925 Effect of Type of Coarse Aggregate on Quality of Concrete; by Stanton Walker.
Concrete Highway Magazine, 7/25, page 168. The conclusion is reached from tests on absorption, compressive strength and resistance to abrasion, that the type of aggregate has little effect on the quality of the concrete, provided the aggregate is clean and durable, and well-graded. (May be obtained from Portland Cement Association, Chicago, Ill.)
- 1925 Putting Slag to Work.
Scientific American, 7/25, page 44. An article drawing attention to the fact that slag, formerly a waste product, is now being put to work, in roofing, as ballast, concrete aggregate, and road-building material, as an ingredient in cements, and in paving blocks. The systems of disposal and processing slag are also covered.
- 1925 Chilton County Concrete Road Attracting Attention.
Industrial Index, 7/29/25, page 50. This article is listed also under date of 2/26/25.
- 1925 Developments in Maintenance of Bituminous Macadam; by John S. Crandell.
American City Magazine, 8/25, page 157. Slag and stone are considered as the aggregate for bituminous macadam construction, and for maintenance of the same. Granulated slag is used for filler in the foundation course. Slag particularly is mentioned as making a good foundation for the road.
- 1925 National Directory of Commodity Specifications; by U. S. Bureau of Standards.
Bureau of Standards, Miscellaneous Publications No. 65, 8/28/25. Book containing an alphabetical list of such commodities as are paid for out of taxes, and a thoroughly

classified list of the specifications for these commodities.
(May be obtained from Superintendent of Documents,
Washington, D. C.)

- 1925 Crushed Stone versus Competing Materials, by Norman Kelb.
Georgia Highways Magazine, 10/25, page 10. The author accepts slag as suitable for non-rigid types of pavement, but is doubtful of its success in concrete, due to high loss by Deval abrasion.

- 1925 Foundations for Asphalt Pavements; by Asphalt Association.
Asphalt Association Circular Number 36, 10/21/25.
This Circular deals entirely with base course construction for asphaltic pavements, black base being given the preference, though the use of a Portland cement concrete base is noted. In this connection, particular attention was drawn to the successful use in the South of a concrete base using slag cement. All the contributors to this Circular advise the use of slag in asphaltic construction. (May be obtained from the Asphalt Association, New York City.)

- 1925 Consideration of Slag for English Tarmacadam; by W. E. Cone.

Roads and Road Construction, 11/1/25. Millions of tons of slag have been used in England in tarmacadam construction. The author is in favor of slow cooling of slag in the cinder ladles, in order to take advantage of "annealing action."

- 1925 Various Foundations for Asphalt Pavements; by Geo. C. Warren.

Canadian Engineer, 11/17/25, page 551. An account of the use of slag cement in concrete bases under asphaltic construction. The absence of cracking in the concrete base was the most noticeable feature. Several roads in Alabama are listed as being of this type of construction.

- 1925 Report on the Report of the Joint Committee; by the Committee on Masonry of the American Railway Engineering Association.

This Committee advised changes in the Joint Committee's Report which would allow of the inclusion of slag as one of the typical concrete aggregates, as in A. R. E. A. specifications. (May be obtained from Amer. Rwy. Engrng. Ass'n, Chicago, Ill.)

- 1925 Available Data on Abrasion; by Fred Hubbard.

Thesis, 12/11/25, summarizing the data on Deval and Talbot-Jones abrasion tests, and on the Arlington Circular Track tests. Contradictory evidence is shown to exist between the findings in the Deval abrasion test and the results when the slag is incorporated in a pavement, as in the Circular Track at Arlington, Va.

- 1926 Specifications for Concrete for the Portland Cement Association Building at Chicago; by Frank McMillan and Stanton Walker.

Proceed. Amer. Concrete Inst., Vol. 22, page 122. The quality of concrete in this building was controlled solely by means of a specification based on the control of the quantity of mixing water. Slag was admitted as one of the available aggregates, but local pebbles were used.

- 1926 Symposium of All Specifications; by National Slag Association.

National Slag Association, 1926. Symposium of all specifications in the National Slag Association files, abstracted and listed alphabetically for quick reference. They include State Highway Departments, Technical Societies and Government Bureaus.

- 1926 Specifications for Local (Pittsburgh) Aggregates.

Engineers' Society of Western Pennsylvania, 1/5/26. The specifications for concrete aggregates admit slag as coarse aggregates.

- 1926 Manufacture, Properties and Tests of Slag; by Fred Hubbard.

Paper, 1/7/26, read before a class in highway engineering and highway transport at University of Michigan, on slag as a highway material. Data is given on sizes, processing, production, and tests of slag—a very complete thesis on the material slag itself.

- 1926 Slag in Road Construction, With Special Reference to the Bituminous Road; by Dr. A. Guttman (Germany).

Report No. 7 of the Committee on the Uses of Blast-Furnace Slag, 1/14/26. This report from the Association of German Iron Works, of which the Committee is a part, notes the various European and American specifications for slag, with a view to making their own more reasonable. It is concluded that slag has particular characteristics, which, if taken advantage of, gives it an advantage over natural rock, and that most slags are suitable for every type of road construction, but particularly the heavy slag. Granulated slag may be used as fine aggregate in concrete construction, with crushed slag as the coarse aggregate.

- 1926 Slag Aggregate Used on Alabama Road Contract; by Allen L. Wallace.

Concrete Highway Magazine, 2/26, page 30. Account of construction of 23-mile stretch of slag concrete pavement in Alabama. Special methods of finishing were employed, in order to get a good surface. Concrete designed for 3,000 lbs. tested 4,300.

- 1926 Ready-Mixed Concrete in Birmingham, Ala.; by W. E. Barker.

Eng. News Record, 2/18/26, page 262. The Sloss-Sheffield Steel and Iron Co., of Birmingham uses their own slag in a ready-mixed concrete plant. The concrete is hauled a maximum distance of 18 miles without noticeable segregation.

- 1926 Summary of Papers Read at American Concrete Institute Annual Meeting.

In the paper, "Concrete Pavement Design," by L. W. Teller and J. T. Pauls, page 314 of the proceedings, Vol. 22, the conclusions from the Arlington Circular Track tests are summarized. In the Report of Committee E-5 on Aggregates, slag is included as a typical aggregate. In the paper, "Control of Concrete Mixtures on the University of Pittsburgh Stadium," W. S. Hindman tells of using granulated slag to a thickness of two feet, surrounding columns of concrete which ran through a coal-seam that was burning in a nearby section. (Proceed., Vol. 22, page 110.)

- 1926 What are the Most Significant Tests for Concrete? by A. T. Goldbeck.

Proceed., Amer. Concrete Inst. Vol. 22, page 386. The author advises specific tests for certain properties expected in the concrete, unless it has been established that high compressive strength, for example, is a measure of the degree of that property desired in the concrete. The author also is of the opinion that the Deval abrasion test is not indicative, in the case of gravel and slag.

- 1926 Historic Slag Road in Missouri; by Prof. C. E. Bardsley.

Widening a Colorado Highway; by Jos. C. Coyle; Highway Magazine, 3/26, pages 59, 61. This issue contains two articles on the use of slag, the first that of a 100-year-old macadam road in Missouri, and the second the widening of a Denver highway with smelter slag in a bituminous mixture.

- 1926 Ballast Committee Report.

Crushed Stone Journal, 3/26, page 1. The report of the Ballast Committee of the National Crushed Stone Association tabulates the replies received from a number of railroads re the respective merits of the different ballast materials. Slag is listed fourth.

- 1926 Dependable Highways; by National Paving Brick Manufacturers' Association.

Booklet published by the authors, 3/26, containing an account of the use of slag in Jamestown, N. Y., for ballasting street car track while repairs were being made. (May be obtained from Nat. Pav. Brick Manufacturers' Ass'n, Engineers' Bldg., Cleveland.)

- 1926 By-Products Help Reduce Ford's Costs; by J. C. Royle.

Cleveland "News," 4/14/26. In the last year, eleven million dollars' worth of by-products were sold by the Ford Company, and blast-furnace slag was used in concrete.

- 1926 Suggests New Deal in City Paving Plans; by H. P. Cummings.

Cleveland "Press," 4/23/26. The author, Paving Expert of the Municipal Research Bureau, criticising the inspection and testing of aggregates on the job, suggests a new force of inspectors as the only remedy for existing condi-

tions, when concrete is laid in freezing weather, on a frozen subgrade, and with too much mixing water. He states that slag is accepted from the materials yards without inspection or test.

- 1926 Salvaging Becomes Huge Industry at Ford's; by Henry Ford. Cleveland "Plain Dealer," 5/2/26. Among other uses of by-products, Ford uses 225 of his 500 tons per day of slag as an ingredient in Portland cement, and the remainder is crushed for roads. The production of cement totals 2,000 barrels per day, and is made by the wet process.
- 1926 Properties and Manufacture of Concrete Building Units; by Frank A. Hitchcock and John R. Dwyer.
Circular No. 304 of U. S. Bureau of Standards, 6/10/26. Concrete block, brick and tile are considered under the headings of materials, proportioning, mixing, molding and curing. The requirements usually demanded of concrete products by building codes are also noted. Slag is one of the aggregates listed. (May be obtained from Superintendent of Documents, Washington, D. C.)
- 1926 Well-Fed Mixers Speed Big Job.
Successful Methods, 7/26, page 24. The Sears-Roebuck building at Atlanta, Ga., is being built of slag concrete, which is mixed in two mixers with a combined daily output of 1,000 cubic yards. The slag is brought to the mixer by conveyor belts from the stock bins, effecting a remarkable labor saving. (May be obtained from the publishers, McGraw-Hill Publishing Co., New York City.)
- 1926 Symposium of All Specifications in the American Society for Municipal Improvements.
Compiled by National Slag Association, 7/26. Specifications for slag are listed for concrete sidewalks, pavements and sewers, and for asphaltic macadam pavement, asphaltic base course, tarbound base course, and bituminous surface treatment.
- 1926 Study of the Mechanical Analysis of Crushed Stone; by W. R. Sanborn and A. T. Goldbeck.
Crushed Stone Journal, 7/1/26, pages 1-8. Mr. Sanborn discussed the efficiency of gyratory crushers and revolving screens as applied to crushed stone, with a view to bringing about a closer understanding between the quarrymen and the engineers who are writing specifications. Mr. Goldbeck offered a table of sizes and gradations for the various uses of stone and slag.
- 1926 Planned Routing of Slag Inspection Trip Through Ohio and Pennsylvania; by National Slag Association.
Compiled by National Slag Association, 9/29/26. The itinerary of the inspection trip through Eastern Ohio and Western Pennsylvania, covering slag roads of every type

of construction, and highway structures. Approximately 700 miles of highway were covered on the trip, a large part of which were of slag construction.

1926 Resurfacing a Brick Pavement with Concrete.

Concrete Highways, 10/26, page 234. An account of the resurfacing of the brick pavement between Cleveland and Berea with slag concrete, extending the width at the same time by $9\frac{1}{2}$ feet with concrete. The thickness of the resurfacing was 6" over the old road and 8" for the widening. (May be obtained from Portland Cement Ass'n, Chicago.)

1927 Utilization of Blast Furnace Slag in Highway Improvement, by Dr. C. E. Bardsley. Technical Bulletin, School of Mines and Metallurgy, University of Missouri, Rolla, Mo. Volume Ten, Number One. November, 1926. History, manufacture, tests, and slag as a structural material for the building of highways. 113 pages.

